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# Jurassic Plants from Kaga, Hida, and Echizen.

By

Matajiro Yokoyama.

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## 1. General Remarks.

Until recently very little was known of the fossil flora of Japan. The first systematic treatment of it is found in the work<sup>1)</sup> of Dr. H. Th. Geyler who, in 1877, described and figured 12 species of Jurassic plants collected by Dr. J. Rein in the valley of the Tetorigawa in Kaga. Three years later the same author in the "Botanischen Mittheilungen"<sup>2)</sup> referred to the occurrence of *Carpinus grandis* Unger in the Tertiary formation of Mikawa<sup>3)</sup> in Honshū.<sup>4)</sup> This was the only literature relating to the fossil flora of our country down to the year 1881, when for the first time, Prof. A. G. Nathorst

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1) Dr. H. Th. Geyler:—*Ueber Fossile Pflanzen aus der Juraformation Japans*, with 11 pages and 5 plates. (Palaeontographica, 1876—1877. vol. XXIV, 5th livr.)

Prof. Dr. D. Brauns mentions in his "Vorläufige Notizen über Vorkommnisse der Juraformation in Japan" (Mittheilungen der deutschen Gesellschaft für Natur- und Völkerkunde Ostasiens, June, 1880, p. 440—442) the following species of plants based on his examination of Dr. Kotō's collection: *Podozamites*, *Asplenium argutulum* Hr., *Thyrsopteris elongata* Geyl., *Adiantites*, *Taeniopteris solitaria* Phill. sp (= *Scolopendrites solitarius* Phill.) and *Ginkgo sibirica* Hr. An examination of the specimens to which these names relate led me to the conviction that Prof. Brauns' *Taeniopteris solitaria* is in reality *Nilssonia ozoana* m., and as to *Ginkgo sibirica* which is mentioned by him, I was not able to find out any specimen undoubtedly referable to that species.

2) Dr. H. Th. Geyler:—*Carpinus grandis* Ung. in der Tertiärformation Japans (Botanischen Mittheilungen in Abhandlungen der Senkenbergischen Naturforschenden Gesellschaft, 1880.)

3) Mikawa is the name of a province. The exact locality is probably *Komura* in *Nishi-kamogōri*, as no other place is as yet known to yield Tertiary plants in that province.

4) The name *Honshū* applies to the main island of Japan and is certainly preferable to any other of the names that are sometimes used.



of Stockholm published a preliminary communication <sup>5)</sup> on more than 70 species of Tertiary plants collected by Prof. Nordenskjöld on his visit to Japan during the famous Vega Expedition around the Asiatic continent. This work was soon followed by a more complete one, <sup>6)</sup> in which leaves collected by Hilgendorf are also described. The work principally treats of the young Pliocene, or, perhaps, the oldest Quaternary flora of Mogi, a very important group, from which the author was able to draw interesting conclusions as to the origin and climatic relations of our recent flora. In this work he also mentions <sup>7)</sup> 12 species of the older Tertiary plants from Ezo (Hokkaido) and Honshū determined by Leo Lesquereux, but which were up to that time yet unpublished.

During the last two years our Geological Survey has sent to Prof. Nathorst a large collection of Tertiary plants for investigation, on a part of which he has already drawn up a brief preliminary report. <sup>8)</sup> These were exclusively from Northern and Central Japan. For the most part they belonged to the older Tertiary, corresponding in age to the floras of Sachalin and Alaska. Prof. Nathorst mentions in this paper plants collected by Mr. Petersen at Nagasaki. About these, and the plants last sent chiefly including those of Shikoku and Kyūshū, he will write other memoirs.

By the study of these fossils we shall be enabled to form quite a comprehensive idea regarding the Tertiary flora of Japan; but as to

5) Dr. A. G. Nathorst :—*Förutskickadt meddelande om Tertiärfloran vid Nagasaki på Japan*. Aftryck ur Geologiska Föreningens i Stockholm Förhandlingar, 1881, No. 68, vol. V, No. 12.

6) Dr. A. G. Nathorst :—*Bidrag till Japans Fossila Flora*. Ur drega expeditionens Vetenskapliga jakttagelser. Stockholm 1882, vol. II, 165 pp. w. 16 pl. 8°—Also in a French translation :—*Contribution à la flore fossile du Japon*, 92 pp. w. 16 pl. 8° (Kongl. Svenska Vetenskaps Akademiens Handlingar, 1883, vol. 20, No. 2).

7) *Contribution à la flore fossile du Japon*, p. 5.

8) Dr. A. G. Nathorst :—*Beiträge No. 2 zur Tertiärflora Japans, Vorläufige Mittheilung*. (Botan. Centralbl. f. d. Gesamtgeb. d. Botanik d. In-u. Auslandes, vol. XIX, 1884, No. 29. Cassel.)

the Mesozoic flora nothing further has been done<sup>8)</sup> since the publication of the work by Dr. Geyler.

Since Dr. Rein's discovery of Jurassic plants, the valley of the Tetorigawa has been twice visited by geologists. The first visit, a very short one, was made in 1880 by Dr. B. Kotō. On his return he made a brief report<sup>9)</sup> accompanied by a sketch map of the river valley and four geological sections. The second and more extensive visit was undertaken by my friend Mr. Tadatsugu Kochibe.

In 1883 the Imperial Geological Survey undertook the reconnaissance of various parts of Central Japan, one of which was a region including the provinces of Kaga, Hida, Echizen and Etchū, between the parallels of 35° and 37° N. Lat. The survey was conducted by my friends, Mr. T. Kochibe as geologist and Mr. K. Kōdari as topographer. This survey which lasted three months brought back many interesting fossils, some of which together with those formerly collected by Dr. Kotō, form the subject of the present paper.

As a detailed account of this survey will appear in future reports of the Geological Survey, I need not dwell on this point more than to indicate briefly the general outline of the geographical and geological features of this part of Japan. This is done from data kindly furnished to me by Mr. Kochibe.

First, as to the geography. A mountain chain beginning with Ishidogiyama in Noto runs nearly due south, with the provinces of Kaga and Echizen on one side, and those of Etchū and Hida on the other. This culminates in Hakusan, a group of volcanoes which rise on the boundaries between Kaga, Hida and Echizen. There are three

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8) A. Schenk, in *Richthofen's China* vol. IV (p. 263, pl. LIV, fig. 1) 1883, described and figured a single specimen of *Thyrsopteris elongata* Geyl. from an unknown locality in Japan.

9) B. Kotō:—*Ishikawa-ken ka Kaga no Kuni Tetorigawa Kinbō Chishitsu Gaisoku*. Published by the Imperial Geological Survey of Japan, 1880, Tōkio.

peaks, viz., the northern or Okunoin 2664 m. high, the southern or Bessan 2376 m. high, and the central or Gozen, which is the highest of all, 2687.5 m.<sup>10)</sup> high. These peaks are for the most part of the year covered with snow, to which fact the origin of the name Hakusan or 'white mountains' is probably due. From this part a range branches off to the west, forming the boundary between Kaga and Echizen, and a little further south, another branch runs in the opposite direction, crossing the boundary between Hida and Mino. For some distance the central range trends southward; then turns to the west and then again to the south. Here it blends with the chain of Ibuki in Omi. The range in Kaga quickly decreases in height as it extends westward, ending in a broad belt of plain running parallel with the coast of that province.

The Hakusan group, occupying the highest part in the whole chain and soaring between the three provinces above named, gives rise to numerous watercourses which feed the Tetorigawa in Kaga, the Kuzuryūgawa in Echizen and the Shirakawa in Hida, all of which empty themselves into the Japan Sea.

The *Tetorigawa* has two sources. A stream that springs in Okunoin called Ozōgawa flows northward and joins with the Haku-sangawa coming from Bessan at Kinameri. The river then runs northward through a narrow valley down to Tsuruki, a little below which it trends to the west, and flowing through a wide alluvial flat finally enters the sea at Yoshikawa, after a course of 20 ri (78 kilom.)

The *Kuzuryūgawa* is fed by three principal streams. One of these, the Ishidoshirogawa, has its source in Bessan and flows southwest from that mountain to Asahi, where it joins with the other two coming from the boundary of Mino. The river then pursues a north-

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10) This is the mean of two barometric measurements by Messrs. Kochibe and Kōlari. These measurements may be considered more accurate than those published hitherto.

westerly direction, and constantly fed by mountain torrents on its way, unites with the Managawa near the town of Ōno. After this confluence the river is called the Asuwagawa, and after its junction at Kumaru, with the Hinogawa, a large river coming from the south, empties itself into the sea at the port of Sakai. The total course of the river is about 32 ri (125 kilom.), for  $\frac{1}{3}$  of which it goes through a plain.

The *Shirakawa* of Hida has two sources. One stream, rising in Bessan, flows easterly until it joins the Shōgawa at Okami. Here the river takes the name of Shirakawa and rushes almost due north through deep ravines for 18 ri (72 kilom.) to the boundary of Etchū, through which province, under the name of the Imizugawa, it runs for 40 ri (157 kilom.), till it enters the Bay of Toyama at the port of Fushiki after a total course of more than 58 ri (230 kilom.).

Secondly as regards the geology, I shall here enumerate the rocks and formations as observed by Mr. Kochibe.

Among the sedimentary rocks we find

1. Crystalline Schists, mainly mica-schist and chlorite-schist, but also serpentine and crystalline limestone, taking only a subordinate part in the formation of the mountain system, and occasionally out-cropping from beneath the younger rocks, e. g., in the valleys of the Tetorigawa, the Shirakawa, and also the Ishidoshiragawa.

2. Sandstones, Clay-slates and Limestones, barren of fossils, but probably referable to the younger part of the Palaeozoic Group. These rocks are exposed only in the southern part of the chain near Mino.

3. Mesozoic Group, consisting of sandstones, shales and conglomerates of the *Jurassic Period*, and occupying a great part

of the system near Hakusan. Very rich in fossils.

4. Tertiary System, consisting of tuffs and sands, and composing lower mountains and hills on the western flank of the chain. A part of these tuff layers contains fruits of *Trapa borealis* Hr.,<sup>11)</sup> and a part, leaves which are probably Pliocene.<sup>12)</sup> The sands are probably younger than the harder tuffs. They are very rich in young marine shells<sup>13)</sup> offering many identical species with those of the environs of Tokyo.<sup>14)</sup>

5. Quaternary System, covering the plains along the coast of Kaga and Echizen which, in the former, consists of heavy clayey loam.<sup>15)</sup>

The eruptive rocks may be described under four groups.

1. Granites, mainly found in Hida, also in patches in Kaga and Echizen. Their exact age is yet unknown, but evidently they are the oldest of all the eruptive rocks, as they are traversed by dykes of porphyries and porphyrites.

11) Dr. A. G. Nathorst:—*Beiträge No. 2 zur Tertiärflora Japans (Vorläufige Mittheilung)*, p. 5.

12) Idem. p. 7. The exact fossil locality is *Ushigatani* from which place Dr. Nathorst mentions *Fagus japonica*; *Mac. fossilis* Nath., *Polygonum cuspidatum* Sieb. et Zucc. *fossile* Nath., and *Phyllites* sp.

13) These fossils I found to belong to the genera, *Tarritella*, *Odostomia*, *Ringicula*, *Pleurotoma*, *Clavatula*, *Terebra*, *Chemnitzia*, *Rissoa*, *Eburna*, *Murex*, *Skenea*, *Trophon*, *Cancellaria*, *Globulus*, *Trochus*, *Valvata*, *Bulla*, *Adeorbis*, *Natica*, *Dentalium*, *Pecten*, *Ostrea*, *Anomia*, *Pectunculus*, *Limopsis*, *Nucula*, *Nuculina*, *Arca*, *Saxidomus*, *Cytherea*, *Maestra*, *Diplodonta*, *Lucina*, *Tellina*, *Cardita*, *Cardium*, *Lasaea*, *Leda*, *Ungulina* and *Venus*. Many of these are identical with those described by Prof. Brauns, the chief of which are *Tarritella communis*, *Pleurotoma tigrina*, *Ringicula areolata*, *Terebra bipartita*, *Eburna japonica*, *Globulus superbus*, *G. monilifer*, *Dentalium entale*, *Pecten plicatus*, *P. inqueatus*, *P. yessoensis*, *Pectunculus glycymeris*, *Nucula Cobboldiae*, *Diplodonta trigonula*, *Lucina borealis*, *Saxidomus purpuratus*, *Cardium Californiense*, *Laercardium bullatum*, *Lasaea rubra*, *Leda confusa*, *Cytherea meretrix* and *Ostrea gigas*, to which are to be added *Dentalium costatum* Sor., *Nuculina ovidis* Wood, *Tellina venulosa* Schrenk., *Arca Kraussi* Phill., *Cardita scalaris* Sor. and *Lucina crenulata* Wood. Besides these there are many species yet undetermined, but decidedly identical with those occurring near Tokyo, among which there may be also forms which are entirely new.

14) Dr. David Brauns.—*Geology of the Environs of Tokio*. Memoirs of the Science Department, Tokio Daigaku, No. 4, Tokio, 188'.

15) B. Kotō:—*Tetorigawa Kibō Chishitsu Gaisoku*, p. 19.

2. **Porphyries and Porphyrites**, forming a considerable part of the mountain chain in Hida and Kaga. One of these (hornblende-porphyrite) also occurs as dykes in the Jurassic rocks, which must therefore be older.

3. **Andesites**, very extensive and covering the Jurassic system. The Hakusan group is made up of these rocks with which the Tertiary tuffs above mentioned may be contemporaneous.

4. **Modern Lavas**, covering the top of Gozen, and also found in valleys beneath in the form of loose pebbles.

The *Jurassic System*, whose vegetable remains are the sole object of the present monograph, extends over the provinces of Kaga, Hida and Echizen, between  $36^{\circ} 20'$  and  $35^{\circ} 50'$  N. Lat., approximately forming a rhombic outline, with one diagonal pointing north and south, and with its sides varying in length from 9 to 10 ri (35—40 kilom.). The general strike of the strata is N.E. with dip to N.W., in most cases very gentle ( $10^{\circ}$ — $15^{\circ}$ ), but sometimes as much as  $70^{\circ}$ . It is as above stated covered with andesites which form a belt over the system crossing it from N.E. to S.W., and also characteristically pierced with dykes of hornblende-porphyry, which Mr. Kochibe observed in several places. The system has also been observed near Kurouchi in Hida, forming a small basin in itself.

The fossils obtained from the system are very numerous. They belong to Ostracoda,<sup>16)</sup> Mollusca,<sup>17)</sup> and plants; the first represented by the genus *Estheria*, and the second, with the exception of a few badly preserved Ammonites, by the genera *Cyrena*, *Corbicula*, *Melania* (?), *Placuna*, *Ostrea*, *Solen* and *Natica*. The first three with many species are abundantly represented by individuals, some of which are

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16) Ostracoda are found at Tanimura in Echizen, Okanigo in Hida and Ichinose in Kaga.

17) Mollusca are found at Kurouchi and Ushimaru in Hida, Kinomeri, Yanagidani, Ichinose and Chūgū in Kaga, and Nochino and Kaizara in Echizen.

of very large size. The last four are scantily represented both as regards species and individuals, thus showing that the system is in great measure of freshwater or brackish origin. But that it is not wholly so is shown by the occurrence of the Ammonites discovered by Mr. Kochibe in a dark clayey shale of Shimoyama in Echi-zen. These animal remains are tolerably plentiful in species, and therefore require a separate treatment. It may be here stated that the shell-layer always occurs below the plant-bed as observed at Ushimaru.

The plant remains are considerably more numerous than those of the mollusca, offering at least a decidedly greater number of species than the latter. They were obtained in several places, which will now be described along with their geological features.

(1.) *Shimamura* (Prov. Kaga), situated on the upper part of the Tetorigawa (the Hakusangawa), about 15 ri (59 kilom.) up the river and 5 ri (20 kilom.) N.W. of Gozen, and 413 m. above the sea-level. Here the fossils occur in yellowish-grey sandstone, sometimes argillaceous and dark-coloured, sometimes reddish and then highly micaceous. They are generally very well preserved. Together with these plants I obtained a single specimen of a Bivalve, which however is too imperfect for correct determination. It may be referable to one of the *Unionidae*.

(2.) *Yanagidani* (Prov. Kaga), situated up the Hakusangawa from Shimamura. Fossils occur in loose pebbles in the river-valley. Mr. Kochibe observed occasionally pebbles containing shells and plants between Ushikubi (about 1 ri above Shimamura and 489 m. above the sea) and Ichinose (about 3 ri above Ushikubi and 814 m. above the sea). The plants are found in grey shaly sandstone. They may be considered only as a portion of the Shimamura flora as the fossils themselves show.

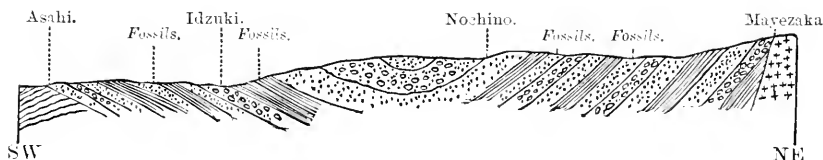







(3.) *Ozō* (Prov. Kaga) on the *Ozōgawa*, a branch of the *Tetorigawa*, about 3 ri (12 kilom.) in direct distance N.E. of *Shimamura*, and 370 m. above the sea-level. Here the fossils are found mainly in black carbonaceous, partly micaceous, sandy shale, from which the plants, which are also black, can hardly be distinguished, unless by their more shining colour; and partly in highly micaceous dark sandstone, which may be considered as differing from the shale in having less clay admixed.

At *Setomura*, a village lying between this place and *Kinameri*, Mr. *Kochibe* observed the following series of rocks :

- a. *Siliceous Sandstone*, grey and medium-grained, underlayed by
- b. *Marly Conglomerate*. The pebbles composing this rock are partly of limestone, which is often dissolved out, leaving cavities. The solution penetrates amongst the combining medium, making the rock harder and harder.
- c. *Black Shale*, which is the lowest, probably corresponding to the fossil bearing rock of *Ozō*.

(4.) *Hakogase* (Prov. Echizen), situated in the upper valley of the *Kudzuringawa*, very near the boundary of *Mino*, and about 10 ri (39 kilom.) S.E. of the town of *Ōno*. The strata are somewhat irregular, but generally strike N.W. with dip, varying from a very gentle one to up to  $76^{\circ}$  at *Mochiana*. The following is a section along the *Ishidoshirogawa* from *Maezaka* (529 m.) to *Asahi* (430 m.), a distance of 2 ri (7.8 kilom.)



	Siliceous Sandstone, medium-grained, firm, with fossil shells.	} Jurassic.
	Siliceous Conglomerate, firm.	
	Clay and Sandy Shale, with fossil shells.	
	Crystalline Schists.	
	Porphyry.	

The plant-fossils occur in yellowish to dark-grey shaly sandstone or sandy shale, and are excellently preserved. They were collected, not in place shown in the section, but very near the village of Hakogase, which is about 2 ri (8 kilom.) S.E. of Asahi.

(5.) *Tanimura* (Prov. Echizen), lying on a road between the town of Katsuyama in Echizen and Ushikubi on the Tetorigawa. It is 6 ri (23 kilom.) south of Shimamura and 293 m. above the sea. Here the system consists of

a. *Sandstone*, argillaceous, dark and also highly micaceous, with nodules of clay-iron-stone, and filled with Ostracoda; often with intercalating layers of black carbonaceous shale with fossil-stems, and of seams of coal. This is the plant-bed of the place, underlayed by

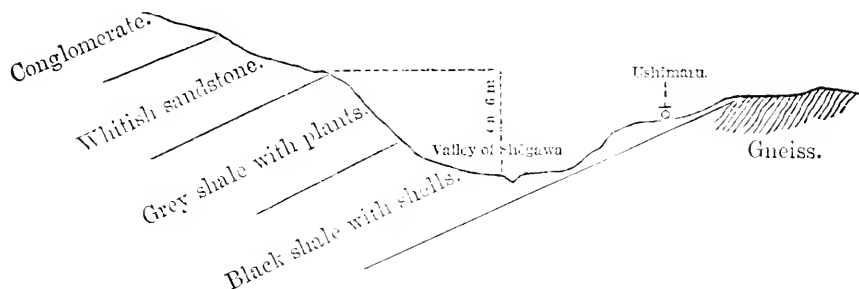
b. *Sandstone and Conglomerate*, the former of a whitish colour and with indistinct prints of plants.

This system at Ushigatani is directly overlaid by nearly horizontal strata of Tertiary tuff to which an allusion has already been made. (See page 6).

(6.) *Okamigō* (Prov. Hida), situated on the Shirakawa, about 1000 m. above the sea, and 5 ri (20 kilom.) east of Hakusan. Here the fossil-bearing rock is dark highly sandy slate, often splitting into thin plates. The fossils are for the most part splendidly preserved.

(7.) *Ushigatani* (Prov. Hida), also on the Shirakawa, about 5 ri

(20 kilom.) S.E. of the preceding place, and 780 m. above the sea-level. Mr. Kochibe observed the following section, with strata striking N.W. and



dipping  $15^{\circ}$  S.W. Here the plant-beds evidently overlie the shell-layer. The fossils are brown-coloured, imbedded in gray shale, which, when weathered, also becomes brownish, so that in this case they are not easily distinguished. Sometimes the shale is somewhat arenaceous and greyish-green in colour.

The species of fossil plants which I have been able to obtain from the above seven localities number in all 45, to which are to be added four others already described by Dr. Geyler,<sup>18)</sup> viz., *Pecopteris Saportana* Hr., *Zamites parvifolius* Geyl., *Cycadeospermum japonicum* Geyl. and *Ginkgo sibirica* Hr.<sup>19)</sup> This makes the total number 49 which may be classified and distributed as follows :

18) Dr. Geyler also mentions *Adiantites amurensis* Hr., *Pecopteris exilisformis* Geyl., and *Podozamites ensiformis* Hr. The first I consider as doubtful, as the pinnules of his specimens show pointed instead of rounded apices. The second I believe to be identical with *Pecopteris exilis* Phill., and the third to be the leaflets of *Podozamites lanceolatus genuinus* Hr.

19) These four species will be considered together with those of Shimamura in the tables, as Rein's descriptions of the fossil locality seem to point to that place.

	Total.	Shima- mura.	Yanagi- dani.	Ozō.	Hako- gase.	Tani- mura.	Oka- migō.	Ushi- maru.
Filices .....	19	14	1	5	6	2	4	1
Rhizocarpeae	1	—	—	1	—	—	—	—
Equisetaceae.	2	—	—	—	—	—	1	1
Cycadeaceae..	15	10	1	4	2	3	5	2
Coniferae ...	10	6	1	2	1	1	4	—
Dubia .....	2	1	—	2	—	—	—	—
	49	31	3	14	9	6	14	4

The next table shows the number of species which each locality has in common with others.

	Total No. of Spec. found.	NUMBER OF SPECIES COMMON WITH							Total No. of Spec. found in other loc.
		Shima- mura.	Yana- gidani.	Ozō.	Hako- gase.	Tani- mura.	Oka- migō.	Ushi- maru.	
Shimamura .....	31	—	3	6	4	6	8	1	14
Yanagidani .....	3	3	—	2	1	2	3	0	3
Ozō .....	14	6	2	—	3	2	5	2	9
Hakogase .....	9	4	1	3	—	2	3	1	4
Tanimura .....	6	6	2	2	2	—	3	0	6
Okamigō .....	14	8	3	5	3	3	—	0	10
Ushimaru .....	4	1	0	2	1	0	0	—	3

Shimamura has given the greatest number of species, of which 45 % are identical with those of other localities. Yanagidani with 3 and Tanimura with 6 species are only parts of the Shimamura flora, as all their species are included in those of the latter. Ozō, with 14 species and 9 in common with others, and Hakogase, with 9 species and 4 in common with others, may safely be considered as contemporaneous with Shimamura. The same is the case with Okamigō, whose species number a little less than one half those of

Shimamura. Okamigō has 8 species in common with Shimamura and 3 with Ozō and Hakogase. Ushimaru up to this time has given only 4 well determinable species, of which 2 are also found in Ozō, so it is probably referable to the same geological horizon as the latter.

Thus we see that the floras of the seven localities of Kaga, Hida and Echizen are so closely related to one another, that they may be considered as forming one great flora that has flourished during the Jurassic period in Central Japan. In giving a general survey of this flora, we have at least five orders of plants to distinguish, viz.,

1. **Filices.** Represented by at least 8 genera and 19 species, 14 of which are Polypodiaceae. All of them except one belong to the well known Jurassic genera *Dicksonia*, *Thyrsopteris*, *Asplenium*, and *Adiantites*, the first with 4 species and the rest each with 3 species. The most interesting species of the first genus is *Dicksonia nephrocarpa*, first found in England, and afterwards in Siberia. The species has been founded on a fertile frond of a fern which strongly resembles that of the recent *Dicksonia culcita* L'Herit. To this are to be added three other Siberian forms, *D. acutiloba*, *D. gracilis* and *D. cfr. Glehniana*. *Thyrsopteris* is at least represented by two already known species, *Th. Murrayana* and *Th. prisca*; the former originally described from Yorkshire, the latter from Kamenka, but both found in Siberia. Very interesting is the discovery of *Asplenium* which all belong to forms already described. Foremost of these is *A. Whitbiense*, which is the fossil of the Jurassic period. No less important are the two others, namely, *A. argutulum* and *A. distans*, both of which are European as well as Asiatic. *Adiantites* are all new; one of them—*A. Heerianus*—showing a fructification like that of *A. capillus-veneris* L. of recent times. The most interesting, however, of all the Polypodiaceae is *Onychiopsis elongata*, a new form of fern with elongated sori strongly suggestive of the recent genera of *Onychium* and *Crypto-*

*gramme*. It is moreover a very important fossil, occurring, as it does, in all the fossil localities—except at Ushimaru where indeed very few species have been found—especially at Shimamura, Okamigō and Tanimura, where it is the most abundant of all. The other genera of this order are *Pecopteris*, *Sphenopteris* and *Macrotaeniopteris*. The first is represented by two important species, *Pecopteris exilis* and *P. Saprota*, both of which have been found in Spitzbergen; the former being originally described from Yorkshire. *Sphenopteris* and *Macrotaeniopteris* are each represented by a single species, the latter probably identical with the Chinese form *M. Richtofeni*.

2. *Rhizocarpeae*. Represented by a single species of *Sagenopteris* resembling very much *Sagenopteris rhoifolia* Presl of the Rhaetic and Liassic of Europe.

3. *Equisetaceae*. Only two species of the genus *Equisetum* which are so far imperfect; one of them however with tubers preserved recalling those of recent species.

4. *Cycadeaceae*. These are nearly quite as numerous as the ferns. They belong chiefly to the family *Zamiaceae*, the foremost of which is *Zamites parvifolius*, so far a strictly Japanese species. The genus with the greatest number of individuals is *Podozamites*, represented by at least 3 species. Of these *P. lauceolatus* with 6 varieties occurs plentifully at Shimamura and Okamigō. It is very important, as it may be called almost cosmopolitan, being found in nearly all the countries where Jurassic flora flourished. Another species of *Podozamites*, viz., *Podozamites tenuistriatus*, may be considered as a very close ally of *P. lauceolatus*, being quite like the latter in form, only with finer veins. Very remarkable are the leaflets of *P. Reinii* which are as numerous as those of *P. lauceolatus*. On the one hand it exhibits nearly rounded leaflets, and on the other, very elongated ones, thus affording passages to that cosmopolitan species through its variety

*oralis*. The genus *Nilssonia* is represented by at least 3 species; one of which, *N. orientalis*, is found both in England and Siberia. It characterizes the flora of Hakogase. The two others are new, one of them *N. nipponensis* being closely akin to *N. acuminata* Schenk of the Rhaetic of Europe. *Anomozamites*, the brother genus of the preceding, is so far very doubtfully represented. Very interesting is the occurrence of a species of *Dioonites* closely related to *D. Brougniarti* of the Wealden. But the most interesting of all is *Dictyozamites indicus* Estm., a genus and species hitherto restricted to the Rajmahal flora of India. It is found great abundance at Ozō. Allied to the preceding, but with coarser veins and nets, is *Dictyozamites grossinervis*, a new species, found at Shimamura. The family of *Cycadeae* is known so far by a seed described by Dr. Geyler under the name of *Cycadeospermum japonicum*, which is the largest known from this order.

5. *Coniferae*. Represented by 6 genera and 10 species, of which 4 genera with 7 species are *Taxaceae*, and the rest, *Abietaceae*. Of the first family the new genus of *Ginkgodium* is the most abundant in individuals. It is closely allied to *Ginkgo*, but decidedly distinguishable by its numerous, simple, parallel veins and its short petiole. So far only a single species has been discovered forming however, a characteristic feature in the flora of Shimamura. The next important genus is the *Ginkgo* itself. Though much less numerous in individuals, it has yielded 3 species, all belonging to forms already described. The most important of these is *Ginkgo digitata* which has been found in Yorkshire, Spitzbergen and Siberia. In the general form of the leaves this species approximates very closely to our living *G. biloba*, however with rarer veins. *G. sibirica* and *G. cf. lepida*, with the lamina separated into many narrow lobes, are closely allied to each other. So far, they are strictly Asiatic. Then



comes *Czekanowskia*, which, though imperfect, seems to be referable to an already known form. The two species of *Taxites*, being present only in isolated leaflets, do not admit of strict specific determination. Much less numerous are the *Abietaceae*, represented by 2 genera and 3 species. The most interesting as well as the most important of these is *Pinus Nordenskjoeldi* which Prof. Schmalhausen brings under his new genus *Cyclopitys* founded on similar leaves found in Siberia which are arranged in whorls around the stem as in our recent *Sciadopitys*. The species occurs in Japan only in isolated leaves, for which I reason have adopted the older generic denomination of Heer. It occurs also in Siberia, Russia and Spitzbergen, and perhaps also in Andö in Norway and Nancy in France. *Pinus* *cfr. prodromus*, obtained so far only in fragments in Japan, has already been found in Spitzbergen and Siberia. The last is the very interesting genus *Palissya*. It is decidedly Rhaetic in Europe, and as a Jurassic plant has hitherto been confined to India—to the three groups of Rajmahal, Kach and Jabalpur. Its discovery in Japan, a country intermediate in climatic conditions between Siberia where the genus is unknown and India where it is known, is of high interest, imperfect though the specimen itself is.

### Conclusion.

Out of the 36 well determined species of plants which Japan has afforded, 20 species have been identified with those already known in other countries. Of these 16 or 80 % are found in the 'Brown Jura' <sup>20)</sup> of Siberia; viz.,

1. *Thyrsopteris Murrayana* Brgt.
2.        ,,       *prisca* Eichw.

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<sup>20)</sup> Dr. Oswald Heer:—*Beiträge zur Jurafloora Ostsibiriens und des Amurlandes*, p. 20. (Mémoires de l'Acad. impér. des Sciences de St. Petersbourg, VII<sup>e</sup> Série, Tome XXII, No. 12 et dernier). *Flora Fossilis Arctica*, vol. IV.

3. *Dicksonia acutiloba* Hr. var.
4.     ,,     *gracilis* Hr.
5.     ,,     *cfr. Glehniana* Hr.
6.     ,,     *nephrocarpa* Bunb.
7. *Asplenium whitbiense* Brgt.
8.     ,,     *argutulum* Hr.
9.     ,,     *distans* Hr.
10. *Nilssonia orientalis* Hr.
11. *Podozamites lanceolatus* Lindl.
12. *Ginkgo digitata* Brgt.
13.     ,,     *cfr. lepida* Hr.
14.     ,,     *sibirica* Hr.
15. *Pinus Nordenskjoldi* Hr.
16.     ,,     *cfr. prodromus* Hr.

With the flora of the same epoch<sup>21)</sup> in Spitzbergen we have 6 species in common that is, 30 % of the indentified species ; viz.,

1. *Pecopteris exilis* Phill.
2.     ,,     *Saportana* Hr.
3. *Podozamites lanceolatus* Lindl.
4. *Ginkgo digitata* Brgt.
5. *Pinus Nordenskjoldi* Hr.
6.     ,,     *cfr. prodromus* Hr.

Our flora has a nearer relation to that of the Yorkshire coast,<sup>22)</sup> distant though it is, having as many as 9 species or 45 % in common. They are the following :—

1. *Thyrsopteris Murrayana* Brgt.
2. *Dicksonia nephrocarpa* Bunb.

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21) Dr. Oswald Heer:—*Beiträge zur fossilen Flora Spitzbergens*, p. 27. (Kongl. Svenska Vetenskaps Akademiens Handlingar, Bandet 14, No. 5). *Flora Fossilis Arctica*, vol. IV.

22) Bath Oolite.

3. *Asplenium whitbiense* Brgb.
4.       ,,       *argutulum* Hr.
5.       ,,       *distans* Hr.
6. *Pecopteris exilis* Phill.
7. *Nilssonia orientalis* Hr.
8. *Podozamites lanceolatus* Lindl.
9. *Ginkgo digitata* Brgt.

With the Chinese and Mongolian Oolitic flora worked out by Newberry,<sup>23)</sup> Schenk<sup>24)</sup> and Schmalhausen,<sup>25)</sup> we have four identifications, *Asplenium whitbiense*, *A. argutulum*, *Macrotacuiopteris* cfr. *Richthofeni* and *Podozamites lanceolatus*; while with the peculiar Indian flora of Kach and Jabalpur<sup>26)</sup> we have only two, *Asplenium whitbiense* and *Podozamites lanceolatus*.

The Jurassic flora of Russia—from the regions of Orenburg and Isjum in its southern part, and from Petschora-Land on the western flank of the northern part of the Ural Mountains—has several species in common with ours. Among the plants mentioned by Eichwald<sup>27)</sup> and Schmalhausen<sup>28)</sup> we find many Japanese forms such as *Asplenium whitbiense*, *A. argutulum*, *Thyrsopteris prisca*, *Podozamites lanceolatus* and *Ginkgo digitata*, which last is an important Oolitic species. Our flora is also allied to that of Andö<sup>29)</sup> and Turkestan,<sup>30)</sup> whence how-

23) J. S. Newberry:—*Description of Fossil Plants from the Chinese Coal-bearing Rocks* in R. Pumpelly's *Geological Researches in China, Mongolia, and Japan*. (Smithsonian Contributions to Knowledge, Jan., 1866.)

24) A. Schenk:—*Jurassische Pflanzen in Richthofen's China*, vol. IV, part. X.

25) J. Schmalhausen:—*Pflanzen aus der nordwestlichen Mongolei*. (Mélange biologique tirés du Bulletin de l'Acad. Impér. d. Sc. d. St. Petersburg, tome XI, March, 1883.)

26) O. Feistmantel considers both Kach and Jabalpur as of Lower Oolitic series. Cf. *Jurassic Flora of Kach*, p. 71. and *Jurassic flora of the Jabalpur Group*, p. 20.

27) E. d'Eichwald:—*Lethæa Rossica*, II.

28) J. Schmalhausen:—*Beiträge zur Jurafloora Russlands*. (Bulletin de l'Acad. Impér. d. Sciences de St. Petersburg, Tom. XI, Jan. 1879.)

29) O. Heer:—*Ueber die Pflanzen-Versteinerungen von Andö in Norwegen*. *Flora Fossilis Arctica*, vol. IV.

30) G. Romanowski:—*Materialien zur Geologie von Turkestan*.

ever we know as yet a comparatively small number of species.

We have still two interesting plants remaining, viz. *Dictyozamites indicus* *Estm.* and a *Sagenopteris*; the first hitherto confined to the Rajmahal or Liassic<sup>31)</sup> flora of India, and the second allied to *Sagenopteris rhoifolia* *Presl* which is also partly Liassic, but principally Rhaetic in Europe. This latter has also been described from the Mesozoic formation of Queensland in Australia, which Feistmantel is inclined to believe to be Liassic.<sup>32)</sup>

From what I have stated above, 19 species or 95 % of those identified have been found in the 'Brown Jura' of other parts of the world, and only 1 species or 5 % in the lower deposits. Therefore, as Dr. Geyler had already done,<sup>33)</sup> *I do not hesitate to conclude that the Jurassic flora of Kaga, Hida and Echizen belongs to the same geological horizon as the floras of Siberia, Spitzbergen, and Yorkshire, namely, to the Bathonian Stage of the Inferior Oolite*, with special relations to the flora of Siberia. This view is moreover justified by the occurrence of *Czekanowskia*, *Taxites* and *Palyssia*, which have their nearest allies in forms already found in the Inferior Oolite.

It may perhaps be urged, that although the plants from most of the localities are decidedly Oolitic, yet Ozō which has given *Dictyozamites indicus* and a *Sagenopteris* allied to *Sagenopteris rhoifolia*, might belong to a horizon somewhat lower than that of the Inferior Oolite. This question, as far as our present investigation goes, must be answered in the negative, as the place has yielded, besides these two

31) Comp. Feistmantel's *Jurassic Flora of the Rajmahal Group*, p. 109.

32) O. Feistmantel:—*Palaeozoische und Mesozoische Flora im östlichen Australien*, Palaeontogr. 1879, Suppl. III, Lief. III, Heft 4, p. 174. In this work the author mentions 6 other species as occurring with *Sagenopteris rhoifolia*, viz., *Sphenopteris elongata* *Carr.*, *Thinnfeldia odontopteroides* *Estm.*, *Cyclopteris euneata*, *Taeniopteris Daentreei* *McCoy*, *Otozamites* *esf.* *Mandeslohi* *Kurr.*, and *Cardiocarpon australe* *Carr.* These are quite foreign to our flora and possess an Indian aspect.

33) Ueber foss. Pflanz. a. d. Juraform. Japans, p. 223.

species, forms which are also found in other localities ; viz., *Onychiopsis elongata*, *Asplenium whitbiense*, *A. argutulum*, *A. distans*, and *Podozamites Reinii*, which are all very important Oolitic types.

Among other interesting forms of the Japanese plants, I may mention *Nilssonia nipponensis* m. closely akin to *N. acuminata* Schenk of the Rhaetic, and *Dioonites Kotoei* m., and *Equisetum ushimarensense* m., resembling respectively *Dioonites Brongniarti* Schenk, and *Equisetum Buchardti* Schimp. of the Wealden. With the Infra-Liassic flora of Tongking described by Zeiller,<sup>34)</sup> we have no species in common, save *Podozamites distans*, which Heer has shown<sup>35)</sup> to be one of the many forms of *Podozamites lanceolatus*.

As seen from a foregoing table, 19 species or 39 % of the whole plants are ferns, 15 species or 30 % cycads, 10 species or 20 % conifers, and the remaining 11 % are taken up by Rhizocarpeae, Equisetaceae and Dubia. Therefore the ferns are the most numerous in the Japanese flora, next to which come the cycads ; while conifers are only half as numerous as ferns. In the Indian flora of Kach and Jabalpur, whence indeed we at present know 48 species of plants, 40 % are cycads, 29 % ferns and 29 % conifers, thus showing a great preponderance of cycads, over the two others. Again, a different order holds in the great flora of Siberia. There, the two able palaeophytologists Heer and Schmalhausen, have already discovered 127 species<sup>36)</sup> of Jurassic plants. Of these, conifers take the lead, making up about 40 % of the whole flora ; while ferns and cycads range a little above 20 %, the former perhaps a little more abundant than the latter. Therefore our own flora may be considered as a

34) Zeiller:—*Examen de la flore fossile des couches de charbon du Tongking* in *Annales des Mines*, 8<sup>e</sup> Serie, tome II, 5<sup>e</sup> livr., 1882.

35) O. Heer:—*Beiträge zur Juraflora Ostsib. u. d. Amurl.*, 1876, p. 107.

36) O. Heer:—*Nachträge zur Juraflora Sibiriens* p. 2 (*Mémoires d. l'Acad. Imp. d. St. Petersbourg*, VII<sup>e</sup> série, Tome XXVII, no. 10). *Flora Fossilis Arctica*, vol. VI.

# Tabular View of the Jurassic Plants of Kaga, Hida and Echizen.

No.	Names	Kaga		Echizen	Hida	Occurrence of identical or allied species in other countries
		Shimonaka	Yanagelumi			
CLASS 1. CRYPTOGAMAE.						
ORDER 1. FILICAEAE.						
Fam. 1. Polypodiaceae.						
1.	<i>Phlegopteris Murakami</i> Brt. ....	-	-	-	-	Siberia, Yorkshire.
2.	<i>pinnatifida</i> Fichw. ....	+	-	-	-	Siberia, Russia.
3.	<i>lugosa</i> nov. sp. ....	+	-	-	+	
4.	<i>Dicksonia gracilis</i> Hr. ....	+	-	-	-	Siberia.
5.	<i>acutifolia</i> Hr. var. ....	+	-	-	-	Siberia.
6.	<i>cf. tibeticum</i> Hr. ....	-	-	+	-	Siberia, Yorkshire (?)
7.	<i>aphanocarpa</i> Fench. ....	+	+	+	-	Siberia, Yorkshire
8.	<i>Oxyphapsis elongata</i> Geyl. ....	+	+	+	+	
9.	<i>Adiantum Heerianus</i> nov. sp. ....	+	-	-	-	
10.	<i>Kochianus</i> nov. sp. ....	+	-	-	-	
11.	<i>laevigata</i> nov. sp. ....	-	-	+	-	
12.	<i>Asplenium ichihouense</i> Brt. ....	+	-	+	-	Siberia, China, Mongolia, India, (Jalsapur and Kach), Yorkshire, Turkestan, Rajmahal
13.	<i>arundatum</i> Hr. ....	+	-	+	+	Siberia, Mongolia, Russia, Yorkshire.
14.	<i>distans</i> Hr. ....	+	-	+	-	Siberia, Yorkshire.
Fam. 2. Sphenopteridaceae.						
15.	<i>Sphenopteris</i> sp. ....	-	-	+	-	<i>Sphenopteris Wellmannii</i> Brt. of Old to and S. Mantelli Brt. of Wealden
Fam. 3. Pecopteridaceae.						
16.	<i>Pecopteris crispa</i> Phill. ....	+	-	-	-	Spitzbergen, Yorkshire.
17.	<i>Sagittaria</i> Hr. ....	+	-	-	-	Spitzbergen.
Fam. 4. Thinnipteridaceae.						
18.	<i>Thinnipteris</i> (?) ....	-	-	+	-	
19.	<i>Macrothinnipteris cf. Ruckthausenii</i> Schenk. ....	+	-	-	-	China.
ORDER 2. RHOZOMARPAE.						
Fam. 1. Salvinellaceae.						
20.	<i>Salvinella</i> sp. ....	-	-	+	-	<i>Salvinella rhodantha</i> Presl. of Liassic and Rhaetic of Europe.
ORDER 3. CALAMITACEAE.						
Fam. 1. Equisetaceae.						
21.	<i>Equisetum ussuriense</i> nov. sp. ....	-	-	-	-	<i>Equisetum Buchardtii</i> Schimpf. of Wealden
22.	<i>sp.</i> ....	-	-	-	+	
CLASS 2. PHANEROGAMAE.						
SUBCL. GYMNOSPERMAE.						
ORDER 1. Cycadopitaceae.						
Fam. 1. Zamiaceae.						
23.	<i>Asplenium orientalis</i> sp. ....	+	-	-	-	
24.	<i>Nilssonia orientalis</i> Hr. ....	-	-	+	-	Siberia, Yorkshire.
25.	<i>acuminata</i> nov. sp. ....	-	-	+	-	
26.	<i>acuminata</i> nov. sp. ....	+	-	-	-	<i>Nilssonia acuminata</i> Gröpp. of Rhaetic.
27.	<i>(?)</i> ....	-	+	-	-	
28.	<i>Dawsonia Kobori</i> nov. sp. ....	+	-	-	+	<i>Dawsonia Brownii</i> Schenk. of Wealden
29.	<i>Zamia perfoliata</i> Geyl. ....	+	-	-	-	
30.	<i>Podocarpus hirsutus</i> Lind. ....	+	-	+	+	Siberia, China, Spitzbergen, Yorkshire.
	var. <i>h. intermedia</i> Hr. ....	+	-	-	+	Siberia, China, Mongolia.
	var. <i>cf. Echinops</i> Hr. ....	+	-	-	+	Siberia, China, Spitzbergen, Russia.
	var. <i>d. minor</i> Hr. ....	+	-	-	-	Siberia.
	var. <i>cf. latifolia</i> Hr. ....	+	-	-	-	Siberia, China, Mongolia.
	var. <i>f. brevis</i> Schenk. ....	-	-	-	+	China.
	var. <i>g.</i> ....	+	-	-	-	
31.	<i>Podocarpus tenuistriatus</i> Geyl. ....	+	-	-	-	
32.	<i>Isom. Geyl.</i> ....	-	+	+	-	
33.	<i>sp.</i> ....	-	-	-	+	
34.	<i>sp.</i> ....	+	-	-	-	
35.	<i>Podocarpus indicus</i> Estm. var. <i>distans</i> ....	-	-	+	-	<i>Podocarpus indicus</i> Estm. Rajmahal
36.	<i>distans</i> nov. sp. ....	+	-	-	-	
Fam. 2. Cycadopitaceae.						
37.	<i>Cycadopitaceae japonicum</i> Geyl. ....	+	-	-	-	
ORDER 2. CONIFERAE.						
Fam. 1. Taxaceae.						
38.	<i>Taxodium Nishida</i> nov. sp. ....	+	+	-	+	
39.	<i>Taxodium distans</i> Brt. ....	-	-	-	+	Siberia, Spitzbergen, Yorkshire.
40.	<i>cf. bipartita</i> ....	-	-	+	-	Siberia.
41.	<i>Sibirica</i> Hr. ....	+	-	-	-	Siberia.
42.	<i>Chamaecyparis distans</i> Hr. (?) ....	-	-	+	+	Siberia, China, Russia, Yorkshire, Rhaetic of Sweden
43.	<i>Taxus</i> sp. ....	-	-	+	+	<i>Taxus brevifolia</i> Nath. of Yorkshire.
44.	<i>sp.</i> ....	+	-	-	-	
Fam. 2. Abietaceae.						
45.	<i>Pinus cf. p. borealis</i> Hr. ....	+	-	-	+	Siberia, Spitzbergen.
46.	<i>Nordenskiöldii</i> Hr. ....	+	-	-	-	Siberia, Spitzbergen, Russia, And? Nancy?
47.	<i>Pinus</i> sp. ....	+	-	-	-	<i>Pinus sibirica borealis</i> Estm. Jalsapur.
INTERETAE SEDIS.						
48.	<i>Palaeobotanites</i> sp. ....	+	-	+	-	Siberia.
49.	<i>Cephalotheca pinifolia</i> nov. sp. ....	-	-	+	-	



kind of connecting link between the northern or Siberian, and the southern or Indian, facies of one great Oolitic flora. The occurrences of Indian elements like *Dictyozamites* and *Palyssia* like-wise hint at the same.

It may be here added, that within a last few years Jurassic plants have been discovered in many other parts of our country. In the Mesozoic basins of Awa and Tosa in Shikoku, plants seem to be tolerably numerous, also animal remains, which are referable to the three main periods of the Mesozoic Era. In the province Kii, to the south of the city of Ōsaka, plants again occur; and this is the case also in the little basin of Kagahara in the province Kōzuke, where however, as far as I know, they are very rare. Jurassic plants have also been brought from the northern part of Shinano, where they were observed in pebbles. These, I hope, will form a subject of another paper on the Jurassic plants of Japan.

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## 2. Description of the Species.

### Class 1. Cryptogamae.

### Order 1. Filicaceae.

### Fam. 1. Polypodiaceae.

### 1. *Thyrsopteris* Kze.

#### 1. *Thyrsopteris Murrayana* Brgt. sp.

Pl. XII, fig. 5.

*Thyrsopteris Murrayana*—Heer, Beitr. zur Jura-flora Ostsib. u. d. Amurl., 1876, p. 30, pl. I, fig. 4, II, 1-4, VIII, 116. Beitr. 1878, p. 1, pl. I, fig. 6. Nachträge, p. 6, pl. I, fig. 1.

*Pecopteris Murrayana*—Brongniart, Veget. Foss. I, p. 358, pl. CXXVI, fig. 1, 4.

*Sphenopteris Murrayana*—Zigno, Enum. Filic. Foss. Oolith., p. 20.

*Hymenophyllites Murrayana*—Zigno, Flora Foss. Form. Oolith., p. 92.

*Tympanophora racemosa*—Lindley and Hutton, Fossil Flora of Great Britain, vol. III, pl. 170.

*Coniopteris Murrayana*—Schimper, Palaeont. Veget., vol. III, p. 471.

This species occurs only in small fragments, one of which I have here figured. It is distinguished from its closely related species, *Thyrsopteris prisca* Eichw. in having the tertiary veins simple. The discovery of undoubted, though fragmentary, specimens of this plant in Japan is very important, as it not only occurs in Siberia, but has already been described by Brongniart and Lindley from the Oolitic flora of Yorkshire.

Loc.—*Okamigō*.

2. *Thyrsopteris prisca* Eichw. sp.

Pl. I, fig. 3, 3a, 4.

*Thyrsopteris prisca*—Heer, Beitr. zur Juraflora Ostsib. u. d. Amurl., p. 86, pl. XVIII, fig. 8. Schmalhausen, Nachtr. zur Juraflora des Kohlenbassins von Kusnezsk am Altai, p. 548, pl. I, fig. 2-4.

*Sphenopteris prisca*—Eichwald, Lethaea Rossica, II, p. 14, pl. IV, fig. 2.

Although our specimens are by no means complete, yet the elongated pinnae, the ovately-triangular and pinnatifid pinnules, and the obtuse lobes, together with the dichotomous tertiary veins, suffice to show that the species, first found at Kamenka and afterwards in Siberia, is also represented in the Japanese Jurassic system. From the preceding species, to which this is very closely akin, it is distinguished in having the tertiary veins dichotomous, as shown in fig. 3a.

Loc.—*Shimamura*.3. *Thyrsopteris Kagensis* n.

Pl. I, fig. 6, 6a. Pl. XI, fig. 7.

*Frond bi-tripinnated; pinnae elongated; pinnules coriaceous, alternate, acutely directed forward, ovate-lanceolate, gradually tapering below and contracted at base, lobed or even pinnatifid; lobes or partitions narrow, acutely directed forward, acute at apex; veinlets dichotomous.*

This fern seems to have been twice to thrice pinnated. Some of the upper part of the upper pinnae show quite an entire margin, while others are furnished with lobes. A pinna in the lower part of the frond (Pl. I, fig. 6, left) however exhibits lobes nearly separate from one another, so that each of them here takes the place of the pinnules above. The substance of the pinnules seems to have been tolerably thick in consistence. A vein given off into each lobe or partition again dichotomizes as represented in fig. 6a. These veinlets

are acutely directed forward like the lobes themselves. A fragment from Tanimura (Pl. XI, fig. 7) with acutely directed, in some cases irregularly lobed pinnules very probably belongs to the some species.

The generic position of this fern is at present uncertain; but the general aspect of the pinnules, and their mode of lobing remind us of many of the *Thyrsopteri* which are widely spread in the Jurassic system. Rare. Loc.—*Shimamura, Tanimura.*

## 2. *Dicksonia* *L'Herit.*

### 4. *Dicksonia gracilis* *Heer.*

Pl. I, fig. 5, 5a. Pl. XII, fig. 13.

*Dicksonia gracilis*—Heer, Beitr. zur Juraflora Ostsib. u. d. Amurl., 1876, p. 92, pl. XVII, fig. 3., Beitr. 1878, p. 13, pl. III, fig. 8-14.

The specimens from both localities represent the upper part of a frond. Although they are rather imperfect, and the impressions more or less indistinct, yet the thickly-set narrow pinnae, with small, broadly lanceolate, oblique, entire-margined, rather acutely pointed pinnules, tend more to point to *D. gracilis* than to its close ally *D. acutiloba* *Heer*. Heer speaks of his *gracilis* as having obsolete and *acutiloba* distinct venation. Just so in our specimens; the venation is in most cases very indistinct. By strong enlargement, however, we can observe faint undivided secondary veins rising acutely from the fine median vein, as shown in fig. 5a.

This species seems to have been very rare. Loc.—*Shimamura, Okamigō.*

### 5. *Dicksonia acutiloba* *Heer* var.

Pl. I, fig. 2a, 2, 1b.

*Dicksonia acutiloba*—Heer, Beitr. zur Juraflora Ostsib, u. d. Amurl., 1876, p. 92, pl. XVIII, fig. 4.

Closely akin to the preceding, but distinguished in having more sharply pointed pinnules and dichotomous secondary veins. A specimen here figured (fig. 2) shows slender pinnae with acutely directed, lanceolate pinnules, which are therefore narrower than the majority of those figured by Heer. They correspond more to those represented in the left-hand extremity of Heer's figure. Fig. 1b shows a fragment of a pinna with long acute pinnules whose inferior veinlets are dichotomous (fig. 2a); so it is probably one of this species. Yet on account of the narrower nature of the pinnules as compared to those described by Heer, I name the Japanese form a variety. Very rare.

Loc.—*Shimamura*.

### 6. *Dicksonia* cf. *Glehniana* Heer.

Pl. XIV, fig. 11, 11a, 12a.

*Dicksonia Glehniana*—Heer, Beitr. zur Juraflora Ostsib. n. d. Amurl., 1876, p. 91, pl. XVII, fig. 4, XVIII, 6, 7.

Heer's diagnosis runs as follows :

“ Frond bipinnated, coriaceous ; pinnae alternate, acutely directed forward, narrow ; pinnules oval, strongly oblique, narrowed at base, decurrent, entire, apex obtuse ; veins very fine.”

In the alternate, obliquely-oval pinnules, obtuse at apex and with simple lateral veins, our specimens agree with the figures and descriptions of Heer, but they are too meagre and fragmentary for an exact determination. The substance of the frond, just as Heer says, seems to have been quite thick. Fig. 11a is an enlarged view of fig. 11, to show the veins more distinctly.

According to the investigations of Prof. Nathorst, this species is doubtfully represented in the Oolite of Yorkshire. Loc.—*Hakogase*.

### 7 *Dicksonia nephrocarpa* Bunb. sp.

Pl. I, fig. 1, 1a.

*Sphenopteris nephrocarpa*—Bunbury, Quart. Journ. of Geol. Soc.,

1851, vol. VII, p. 179, pl. XII, fig. 1a, 1b.

*Dicksonia clavipes*—Heer, Beitr. zur Juraflora Ostsib. u. d. Amurl., 1876, p. 33, pl. II, fig. 7, 7b.

On a small piece of sandstone from Shimamura, there occur fertile pinnae of a fern, which possess comparatively large, kidney-shaped sori 1.5—2 mm in breadth, each of which is borne at the apex of a short lobe more or less narrowed towards the base. Under a magnifier, a vein is seen going into each sorus, sometimes giving off delicate lateral veinlets (fig. 1a).

These pinnae no doubt belong to a *Dicksonia* which is at least very closely allied to *D. clavipes* Hr. from Kaja in Siberia (Beitr. 1876, p. 33). This latter species is considered by Prof. Nathorst as identical with *Sphenopteris nephrocarpa* Bunb. from the Oolite of Yorkshire. To this opinion Heer assents in his Nachträge, p. 6. As I see no sufficient character to separate the Japanese from the Siberian fossil, I identify them, and following Heer (Nachtr., p. 6) in the denomination of the species, I call it *Dicksonia nephrocarpa* Bunb. *sp.*

To this group may be referred the fertile pinnales figured by Oldham and Morris as *Sphenopteris Banburyana* (*The Flora of the Rajmahal series, pt. XXXII fig. 5, 6, 7*), which Feistmantel includes, together with our present species, under *Hymenophyllites* Göp. (*Jurassic Flora of the Rajmahal Group, p. 26-27*). Loc. Shimamura.

### 3. *Onychiopsis m.*

Fertile segments different from the sterile. Sori terminal, linear, on each side of the midrib, parallel with the margin, involucrate; the involucre of each side confluent over the midrib.

This new genus, which I have founded on a plant first described by Dr. Geyler under the name of *Thyrsopteris elongata* and afterwards

mentioned by myself as *Dicksonia elongata* in the Bulletin, shows a fructification apparently resembling that of *Cryptogramme* R. Br. and *Onychium* Kaufl. of the recent flora. The sori were probably linear, placed on each side of the midrib as in *Onychium*. The involucrum may possibly have been formed of the rolled-up margin of the segment or pinnule as in *Cryptogramme*. The general appearance of the fertile segments and the terminal nature of the sori remind us strongly of the latter genus.

*Onychiopsis* may provisionally be treated under *Polypodiaceae*, in the neighbourhood of the tribe *Pteridæ*, until the discovery of sporangia points out its true systematic position among the ferns.

### 8. *Onychiopsis elongata* Geyl. sp.

Pl. II. fig. 1—3. Pl. III. fig. 6 d. Pl. XII. fig. 9, 10.

*Frond slender, bi-tripinnated: sterile pinnae alternate or rarely opposite, elongated, their length rapidly increasing towards the lower part of the frond: pinnules alternate, acutely directed forward, lanceolate or linearly-lanceolate, entire or lobed or even pinnately parted: lobes or partitions acute at apex and acutely directed forward just like the pinnules themselves. Venation obsolete, secondary veins simple, each going into a lobe. Fertile pinnules elongated, with a linear terminal sorus on both sides of the midrib.*

*Thyrsopteris elongata*—Geyler, Ueber foss. Pflanzen a. d. Juraform. Japans, p. 224, pl. XXX, fig. 5. XXVI. 4.5. Schenk in Richthofens China, vol. IV, part X, p. 263, pl. LIV, fig. 1.

*Dicksonia elongata*—Yokoyama, On the Jurassic Plants of Kaga, Hida and Echizen (Bull. Geol. Soc. Japan, part B, vol. I, No. 1) p. 6.

This plant seems to have been very slender and graceful in general appearance, with twice to thrice pinnated fronds whose lightly bent pinnae are in most cases set alternately along a slender rhachis (fig. 2,

Pl. II). The pinnules are much elongated, being longest near the base of the pinna. They are quite entire in the upper pinnae, but become lobed as they get downward, and the incision between the lobes becomes deeper and deeper, so that at last the individual lobes look quite like the pinnules of the upper part of the frond. Fig. 3, Pl. II, represents a pinna belonging to the lower part of the frond, whose extremely elongated pinnules give such an appearance as above alluded to; fig. 3a is an enlarged view of a part of one of them. The length of a pinnule here attains about 37 mm, the breadth being only 3 mm. Fig. 10, Pl. II also represents an inferior pinna.

Along with these sterile pinnae are found fertile pinnules which are either borne quite on a separate pinna or, as is sometimes the case, mixed with the sterile pinnules (comp. fig. 1, 4 a, b, Pl. II, fig. 6d, Pl. III, fig. 9, Pl. XII). The sori are placed two at the end of each pinnule which is considerably narrowed looking like a winged stalk. These double sori are opposite, elongated, linear, meeting each other along the midrib.

This splendid fern is the chief and characteristic fossil of the Japanese flora, being found in all of the fossil localities.

#### 4. *Adiantites* Göp.

##### 9. *Adiantites* Heerianus m.

Pl. XII, fig. 1, 1a, 1b, 2

*Pinnae elongated: pinnules alternate, acutely directed forward, rhomboidal, attenuated below, acute at apex, acutely lobed: veins equal, fine, repeatedly dichotomous*

The four pinnae shown in fig. 1 and 2, I believe, to belong together. The pinnules are, as a general rule, obliquely rhomboidal in shape, attenuated towards the base, and acutely pointed at the apex. They are mostly acutely lobed, but becoming entire and more lanceolate in

shape towards the upper part of the pinnae. As to the venation, no distinct median vein is observable, but the veins are fine, nearly equal in size, and several times forking (fig. 1a). Pinnules of a pinna lying in the middle of fig. 1 show dark spots around their margin, which are probably due to the presence of fruit-dots. Each of these dots or sori seems to have been borne on the tip of each lobe at the ends of veins (fig. 1b), just as in the recent *Adiantums* of the group of *A. capillus-reneris* L. Therefore our plant, together with *Adiantites Schmidtianus* Hr. (*Beitr. zur Jurafloora Ostsib. u. d. Amurl.*, 1876, p. 36, pl. II, fig. 12, 13), in which Heer observed a similar kind of fructification, very probably belongs to the genus *Adiantum*. However as *Dicksonia* in a fossil state sometimes shows quite a similar looking fructification, it may be most prudent at present to refer our fossil to the provisional genus of *Adiantites* Göp.

This species may be compared to *A. nymphaeum* Hr. (*Beitr. zur Jurafloora Ostsib. u. d. Amurl.*, 1876, p. 93, pl. XVII, fig. 5) which, however, has obtusely lobed pinnules.

Rather rare.

Loc.—Shimamura.

I may here notice that the pinnae figured as *Adiantites amurensis* Hr. by Dr. Geyler (*Foss. Pflanz. a. d. Juraform. Japans*, p. 225, pl. XXXI, fig. 2, 3) seem to possess pinnules, most of which are acute at the apex and are quite different from those figured by Heer (see *Beitr.* 1876, pl. XXI, fig. 6 a d). I doubt whether they do not belong to *Heerianus* m. although it cannot be positively decided, so imperfect are the Geyler's specimens.

# 10. *Adiantites Kochibeanus* m.

Pl. I, fig. 7, 7a.

Frond pinnated: pinnae elongated; pinnules alternate, acutely directed forward, entire, broadly lanceolate, cuneate at base, acute at apex:



*veins many, equal, divergent, repeatedly dichotomous.*

This fern seems to have been pretty slender in its general appearance. Along a rhachis, which is by no means strong, are arranged alternate or opposite, elongated pinnae more or less directed forward, but often bent apparently by the weight of ovately or obovately lanceolate, thick, entire pinnules, which are tolerably acutely directed forward. Veins are pretty distinct, and radiate towards the apex and margin of the pinnules, two to five times forking on their way (fig. 7a).

This species is closely related to the preceding in the form of the pinnules which, however, are not in this case lobed.

Very scarce.

Loc.—*Shimamura.*

# 11. *Adiantites lanceus* m.

Pl. XIV, fig. 3, 3a.

*Pinnules alternate, acutely directed forward, lanceolate, acute at apex, constricted at base, entire: veins numerous, equal, divergent, repeatedly dichotomous.*

Along a slender rhachis, are arranged lanceolate pinnules which are tolerably acutely directed forward. At the base they are sensibly narrowed and apparently provided with a short petiole. They appear to have been thin in texture, with numerous distinct veins diverging towards the apex and margin, and repeatedly dichotomizing on their way (fig. 3a), reminding us of the venation of many of the recent *Adiantums*. None of the pinnules in our specimen are perfect; but in two of them, in which the apex and base are preserved, the length measures 50—42 mm. and the breadth  $6\frac{1}{2}$ —7 mm.

I know none among the Mesozoic plants which can aptly be compared to this species. The preceding species, to which it bears some resemblance in form of the pinnules and the mode of venation, has

much smaller pinnules and less numerous veins, and is in general more strongly built.

Very rare ; I possess only a single specimen, the one here figured.

Lec.—*Hakogase*.

## 5. *Asplenium* L.

### 2. *Asplenium whitbiense* *Brøgt. sp.*

Pl. III, fig. 3. Pl. X, fig. 1, 2 a.

*Asplenium whitbiensis*—Heer. Beitr. zur Juraflora Ostsib. u. d. Amurl., 1876, p. 38, pl. I, fig. 1 c, III, 1-6. p. 94. XIV, 8, XX, 1, 6. XXI, 3, 4, XXII, 4 g. 9 c. Beitr. 1878. p. 3, 15, pl. II, fig. 14-17. Nachtr. p. 7. Schmalhausén, Beitr. zur Juraflora Russl., p. 17, pl. II, fig. 1-10, XIV, fig. 4, 5. Schenk in Richthofen's China, vol. IV, part X, p. 246, pl. XLVI, fig. 5, 6, 7, XLVIII, 3-5, XLVIII, 1-4, XLXIX, 4a, 6b, p. 247, pl. XLVIII, fig. 5a, p. 253, pl. LII, fig. 1-3.

*Pecopteris whitbiensis*—Brongniart, Veget. Foss. p. 231, pl. 109, fig. 2-4. Lindley and Hutton, Fossil Flora. Vol. II, p. 145, pl. 134. Newberry in Pumpelly's Geological Researches in China, Mongolia and Japan, p. 122, pl. IX, fig. 6.

*Alethopteris whitbyensis*—Feistmantel, Fossil Flora of Jabalpur Group, p. 87, pl. II, pg. 2-7. Fossil Flora of Kach, p. 22, pl. III, fig. 1-4.

*Alethopteris indica*—Feistmantel, Fossil Flora of Rajmahal Hills, p. 37, pl. XXXVI, fig. 4a, pl. XLVI, fig. 3-4.

Although our specimens are by no means well preserved, yet the short and more or less falcate pinnules show us that we are dealing with the wide-spread *A. whitbiense* *Brøgt. sp.*, and indeed with the variety *tenue* of Heer.

The specimens from Ozō have the pinnae a little more acutely directed forward than in the typical forms, with some of the falcate and blunt pinnulae more closely set together, thus reminding us also of the sterile pinnulae of *Pecopteris Williamsonis* Brgt. (e. g. Hist. Végét. Foss., pl. CX, fig. 12) the original specimen of which I had an opportunity of examining in the museum of Stockholm.

Loc.—*Shimamura, Ozō.*

### 13. *Asplenium argutulum* Heer.

Pl. III, fig. 1. Pl. XII, fig. 8. Pl. XIII, fig. 9. Pl. XIV, fig. 2.

*Asplenium argutulum*—Geyler, Ueber foss. Pflanz. a. d. Juraform. Japans, p. 225, pl. XXXI, fig. 1. Heer, Beitr. zur Juraflora Ostsib. u. d. Amurl., 1876, p. 41, pl. III, fig. 7, p. 96, pl. XIX, fig. 1-4. Schenk in Richthofen's China, vol. IV, part X, p. 246, pl. XLVI, fig. 2-4. Schmalhausen, Beiträge zur Juraflora Russlands, p. 23, pl. II, fig. 12.

This species is a close ally of the preceding, but with pinnules narrower, straighter, and more acute at apex. A specimen from Shimamura (Pl. III, fig. 1) shows some of the pinnules crenulate, on which account it may be prudent for the present to consider it as a variety. That from Hakogase figured in Plate XIV has also a great resemblance to some forms of *Pecopteris Phillipsii* Brgt. = *P. exilis* Phill. (comp. Brongniart, Hist. Végét. Foss., pl. CIX, fig. 2).

This species like the preceding has a wide geographical distribution, as it is also mentioned from Yorkshire by Prof. Nathorst.

Not frequent. Loc.—*Shimamura, Ozō, Hakogase, Okanigō.*

### 14. *Asplenium distans* Heer.

Pl. III, fig. 2. Pl. XI, fig. 4. Pl. XIII, fig. 4. Pl. XIV, fig. 1.

Fond pinnated; pinnae elongated; pinnules either free or united at base, lanceolate, entire, more or less falciform, acute at apex;

10-20 mm. long, 4-6 mm. broad; secondary veins fine, acutely directed forward, dichotomous. (Heer).

*Asplenium distans*—Heer, Beitr. z. Jurafflora Ostsib. u. d. Amurl, 1876, p. 97, pl. XIX, fig. 5-6.

*Pecopteris recentior*—Phillips, Geology of Yorkshire, p. 119, pl. VIII, fig. 15? Zigno, Flora Foss. Form. Oolith. I, p. 195.

*Neuropteris recentior*—Lindley and Hutton, Fossil Flora, vol. I, p. 195, pl. 68. Göppert, Syst. Filic. p. 205. Unger, Gen. et Spec. Plant. Foss. p. 85. Sternberg, Flora der Vorwelt, II, p. 76.

*Cladophlebis recentior*—Brongniart, Tabl. Gen. Végét. Foss. p. 105.

*Alethopteris recentior*—Schimper, Pal. Végét. vol. I, p. 566.

*Pteris recentior*—Ettingshausen, Farn. d. Jetztwelt, p. 113.

This species is distinguished from the preceding by having longer and narrower pinnules, and more delicate secondary veins directed more acutely forward.

The pinnules are entire and attached to the rhachis by their whole base. This is seen in every one of the specimens here figured. In a specimen from Shimamura (Pl. III, fig. 2) which may be considered the best we possess, the pinnules are quite free from one another, the longest measuring 19 mm. in length and  $5\frac{1}{2}$  mm. in breadth. Veins are here very distinct. They are delicate, all dichotomous and acutely directed forward. A specimen from Ozō (Pl. XIII, fig. 4) is only a fragment from the upper part of a pinna; but it is readily recognised by the acute course of the veins. That from Hakogase is much better as far as the number of pinnules preserved is concerned; but all of them are more or less wanting along their margins, so that they look more slender than they really are. Their slightly contiguous nature at the base, and their falcate shape are, however, perhaps best shown in this specimen (Pl. XIV, fig. 1). The Ushimaru specimen (Pl. XI, fig. 4) is also a fragment like that from Ozō. I possess

another from the same locality with more pinnules preserved ; but they are so mutilated, and in part so indistinct, that I thought it not worth while to figure it along with decidedly better, though more fragmentary, specimens.

This species described from Gristhorpe and the Amoor regions, though obtained from the four localities, seems to have been frequent in none of them.      Loc.—*Shimamura, Ozō, Hakogase, Ushimaru.*

## Fam. 2. *Sphenopterideae.*

### 6. *Sphenopteris* Brgt.

#### 15. *Sphenopteris* sp.

Pl. XIV, fig. 13, 13 a.

I obtained only a fragment of this fern, which I believe is to be placed in the group of *Sphenopteris Davallioides* Schimper. My specimen belongs to the upper extremity of a frond, or perhaps of a primary pinna, and shows five long linear pinnules, two on each side and one at the apex. These pinnules are all close together, obtuse at the apex and acutely directed forward. They measure about 7 mm. long and only 1 mm. broad, each pierced with a single delicate vein in the middle (fig. 13 a, enlarged).

I know none among the Oolitic plants that can aptly be compared to this species, except *Sphenopteris Williamsonis* Brgt. from Yorkshire (Lindley, *Fossil Flora*, p. 131, pl. 131), the greater part of the group of *Davallioides* being hitherto known from the Palaeozoic flora. Our plant is also not unlike *Sphenopteris Mantelli* Brgt. of the Wealden (Schenk, *Flora d. Norddeutschen Wealdenform* p. 208, pl. XXI, fig. 6) in the formation of the pinnules (comp. 6 a, pt. XXV of Schenk). However our specimen is too imperfect for a strict specific determination.

Loc.—*Hakogase.*

**Fam. 3. Pecopterideae.****7. Pecopteris Brgt.****16. Pecopteris exilis Phill.**

Pl. I, fig. 8-10, 9a.

Frond tripinnated; pinnae elongated; secondary pinnae also elongated, linear, opposite or alternate, a little directed forward; pinnules entire, oblong, obtuse, close together, free, but contiguous at base in the upper pinnae; median vein distinct, evanescent.

*Pecopteris exilis*—Phillips, Geology of Yorkshire, p. 119, pl. VIII, fig. 16. Bunbury, Quart. Journ. Geol. Soc. 1851, VII, p. 188, pl. XIII, fig. 5 a. 56. Heer Beitr. zur Foss. Flora Spitzb. p. 29, pl. VI, fig. 1, 16. Zigno, Flora Foss. Form. Oolith I, p. 144. Schimper, Pal. Végét. vol. I, p. 536.

*Pecopteris obtusifolia*—Lindley and Hutton, Fossil Flora, vol. III, pl. 158.

*Pecopteris exiliformis*—Geyler, Ueber foss. Pflanz a. d. Juraform, Japans, p. 226, pl. XXX, fig. 1 a.

This species, first found in Yorkshire and afterwards in Spitzbergen, is also represented in the Japanese flora. Fig. 9 shows a specimen in which two primary pinnae are preserved. These pinnae possess long linear secondary ones which are often curved and provided with alternate oblong obtuse pinnules, exactly agreeing with the figure of Lindley. Pinnae of the second order measure 15-20 mm. in length and 4-5 mm. in breadth; but they become much shorter above where they appear creuate, owing to the contiguous state of pinnules at their bases. The rhachises (fig. 9.) which are by no means strong are slightly geniculate, especially in a pinna represented on the right-hand side of the figure; but I believe this to be no permanent character of the plant.

Fig. 8 and 10, both exhibiting crenate pinnae, probably belong to the same species. The latter figure represents a rather indistinct specimen. It shows, however, a primary rhachis which, when compared with that of the second order, may be called pretty strong. It is by no means weaker than that of an English specimen figured by Lindley, as the latter might represent a part of a frond lying lower in position than our own.

Venation is indistinct, save a median vein which is in most cases very clearly seen. It is comparatively delicate, disappearing near the apex of the pinnules (fig. 9a).

What Dr. Geyler described as *Pecopteris exiliformis* from the Tetorigawa-valley is, I dare say, no other than the present species. He considers his plant to be more slender in general appearance than the Scarborough species; but his figures as well as my own only show the upper parts of primary pinnae, while conversely the figure of Lindley represents only their lower parts. Be that as it may, after a careful comparison between my specimens and Lindley's figures, I could find no character sufficient to separate the Japanese from the English species.

Banbury observed in a pinnule of this fern capsules arranged in a single row on each side of a midrib (*Quart. Journ. Geol. Soc.*, 1851, p. 188, pl. XIII, fig. 5a, b), a fructification which he compares with that of *Ancimia* and *Mohria* among *Schizaeaceae*.

Rarely found at *Shinamura*.

## 17. *Pecopteris Saportana* Heer.

*Pecopteris Saportana*—Geyler. Ueber foss. Pflanz. a. d. Juraform. Japans, p. 226, pl. XXX, fig. 4. Heer. Beitr. zur foss. Flora Spitzb., p. 29, pl. VI, fig. 4-7a. VII. 46.

This species was described by Geyler, but not a single new specimen was obtained referable to it.

#### Fam. 4. Taeniopterideae.

##### 8. Taeniopteris *Brgt.*

##### 18. Taeniopteris (?)

Pl. X. fig. 2c.

A very small fragment of a fern (?) from the above locality situated by the side of *Nilssonia ozoana* m. shows very fine curved veins which are often found to fork, when examined with a magnifier, just as in *Taeniopteris densinervis* Feistmantel (*Jurassic Flora of Kach.* pl. II, fig. 6a). The specimen, however, is too meagre even for a certain generic determination.

Loc.—Ozō.

##### 9. Macrotaeniopteris Schimp.

##### 19. Macrotaeniopteris cf. *Richthofeni* Schenk.

Pl. III, fig. 4. 5.

Frond elongated, entire, acuminate at apex; secondary veins numerous, dense, rising at acute angles at base and then becoming horizontal towards the margin, simple or dichotomous.

The two figures above cited represent two faces of the same leaf. It is a fragment, belonging to the apical part which is long drawn out. The specimen measures about 27 mm. in breadth near its base, from which place it appears to taper downward. Therefore the frond is not a large one such as is possessed by many of the species described under this genus. The midrib is rather weak and gets weaker towards the apex. The secondary veins are dense, many of which furcating near the point of rising along the midrib, but many also remaining simple for their whole length. Very rarely, forking takes



place after they have gone on for a considerable distance towards the margin.

Our plant shows a great resemblance to *Macrotæniopteris Riehtofeni* Schenk (*Riehtofen's China* vol. IV, pl. LI, fig. 4, 6) in having acuminate fronds and numerous dense veinlets, with which I indeed compare it, notwithstanding the somewhat smaller size of frond.

Loc.—*Simamura*.

## Order 2. Rhizocarpeae.

### Fam. 1. Salviniaceae.

#### 1. *Sagenopteris* Presl.

#### 20. *Sagenopteris* sp.

Pl. X, fig. 3, 3a.

On a piece of black sandy shale from Ozō there lie a few scattered fragments of longly-obovate leaflets with an evanescent median vein and numerous fine veinlets, radiating towards their margin and forming, as they go, much elongated nets or areoles. The leaflets are more or less oblique in shape, and acute at apex. These characters at once show that we are dealing with a species of *Sagenopteris* that is at least very closely allied to *S. rhoifolia* Presl., under which name indeed I mentioned it in Bull. Geol. Soc. Japan, Part B, Vol. I, No. 1, p. 6. But now I am of opinion that it is better to consider these fragments under the simple name of *Sagenopteris* sp.

Loc.—*Ozō*.

## Order 3. Calamarieae.

### Fam. 1. Equisetaceae.

#### 1. *Equisetum* L.

21. *Equisetum ushimarense* m.

Pl. XI, fig. 1—3.

*Rhizome ribbed ; tubers roundly ovate, single or joined like beads..*

The three specimens here figured I believe to belong to one and the same species. They all represent underground stems which are generally slender. In fig. 3, these stems measure  $1\frac{1}{2}$ —2 mm. in breadth with internodes 15—20 mm. in length, and are seen with 2—3 strong ribs. Tubers are of various shapes owing to distortions under pressure ; but in general they are roundish or roundly-ovate and single or rarely joined like beads. (Fig. 3, small ones on the left). In fig. 3, the diameter of these tubers is approximately 5—9 mm, while in fig. 2 (right) a slender rhizome only 1 mm. broad possesses a large tuber 15 mm. long and 13 mm. broad, in fact the largest we have. Fig. 1 shows comparatively a broad rhizome (5 mm.) with 3—4 strong ribs and a tuber 8—11 mm. in diameter. Sometimes these underground stems are still seen with root-hairs attached.

It is much to be regretted that no overground stem was found with these remains.

*Equisetum Buchardti* Schimp. (*Schenk, Flora der nordwestdeusch. Wealdenform.*, p. 205, pl. XXII, fig. 1—5) from the Wealden exhibits quite a similar kind of spherical tubers which are said to have been tridentate at the apex. An Oolitic species with tubers has been described by Heer (*Beigtr. z. Jurafloa Ostsib. u. d. Annul.*, 1876, p. 99, pl. XXII, fig. 5—7) from Bureja, which however had them more elongated than in our own.

Numerous in a greenish-grey arenaceous shale at *Ushimaru*.

22. *Equisetum* sp.

Pl. XII, fig. 7.

Only a small fragment of an overground stem was obtained,

which is 11 mm. broad and provided with numerous fine crowded longitudinal striae. It is too imperfect for specific determination, but that it is one of the Equisetaceous plants is shown by the presence of a joint.

Loc.—*Okamigō*.

## Class. 2. Phanerogame.

### Subclass 1. Gymnospermae.

#### Order 1. Cycadeaceae.

##### Fam. 1. Zamieae.

#### 1. *Anomozamites* Schimp.

##### 23. *Anomozamites* sp.

Pl. VII. fig. 1d.

A rather imperfect specimen of a leaf of an *Anomozamites*, or perhaps, of a *Nilssonia*, with subopposite quadrangular segments rounded at angles and possessed of fine simple parallel veins, looks not unlike some of the figures of *A. inconstans* Göp. from the Infra-Liassic series of Tongking (Zeiller, *Examen de la flore fossile des couches de charbon du Tongking*, pl. XI. fig. 7), and also those of *Nilssonia comitula* Heer (*Beitr. z. Juraflore Ostsib. u. d. Amurl.*, 1878, pl. IV. fig. 12, 13) from the Lena regions in Siberia. However, a positive determination must be postponed until better specimens are obtained.

Loc.—*Simamura*.

#### 2. *Nilssonia* Brgt.

##### 24. *Nilssonia orientalis* Heer.

Pl. XIV. fig. 4-9.

Leaf entire or rarely segmented, truncated at apex, rounded at base; veins fine, dense, slightly curved and directed forwards.

*Nilssonia orientalis*—Heer, Beitr. z. Juraflora Ostsib, u. d. Amurl., 1878, p. 18, pl. IV, fig. 5-9.

Specimens of a *Nilssonia* represented in the above cited figures are, I believe, to be identified with what was described by Heer as *N. orientalis* from Ajakit on the Lena in Siberia. Our specimens are all entire-margined, which though variable in form, always possess a truncated apex. Fig. 5, though broken, shows an entire leaf which is about 23 mm. broad and only 44 mm. long; so it is tolerably short. Fig. 4 represents a large leaf, 25 mm. broad with 46 mm. of the length preserved; therefore it is probably a much longer leaf than the above. In all of our specimens the veins, which are curved and directed forward, are densely crowded, occurring as many as four to the millimetre, and thus exactly agreeing in venation with the Siberian specimens.

Every one of our specimens shows a strong convexity on the upper surface of the leaf, and a sharp edge on the rhachis where the blades meet from both sides. Sometimes a leaf is found quite doubled over.

Heer compares this species to *N. polymorpha* Schenk of the Rhaetic flora of the Franconia and Sweden, the entire forms of which indeed the Japanese leaves in some cases resemble. Yet a decidedly denser state of veins distinguishes the latter from the Rhaetic species.

According to the investigations of Prof. Nathorst, this species also occurs in the Oolite of Yorkshire.

Very numerous at *Hakogase*, though mostly fragmentary, and forming there the most abundant fossil.

## 25. *Nilssonia ozoana* m.

Pl. X, fig. 2b, 11-14.

*Leaf elongated, entire or rarely segmented, parallel-sided, rounded at apex; veins very fine, dense, perpendicular to the rhachis.*

This species at first sight reminds us of the genus *Tacniopteris* among ferns, but is decidedly different from that genus in having the blade of the segments inserted on, and not laterally to, the rhachis. The leaf seems to have been in most cases entire, with sides strictly parallel except near the apex, where it is sometimes seen slightly to taper (fig. 11). Fig. 12 shows such a parallel-sided leaf. It is 58 mm. long and about  $12\frac{1}{2}$  mm. broad without any appreciable difference in breadth in its upper and lower extremities. Fig. 14 shows a narrower leaf which measures 9 mm. in breadth. But that the leaves were not always entire is shown by fig. 2 b, which represents one side of a leaf divided into rectangular segments about 8 mm. broad. The veins are very fine and dense, about four to the millimetre. They are very faint, and almost obliterated in fig. 11, but are distinct in fig. 13 and 14.

Leaves are in most cases strongly convex on their upper surface along the rhachis, but concave on both sides of it, as is seen in fig. 13 and 14.

This species is allied to the preceding in having very dense veins and generally entire leaves, but is distinguished in having the former strictly at right angles to the rhachis and the latter narrower and more elongated.

Fragments are frequent at Ozō.

## 26. *Nilssonia nipponensis* m.

Pl. VI, fig. 8d. Pl. VII, fig. 2-7, 8a. Pl. XII, fig. 6.

Pl. XIII, fig. 1.

*Leaf petioled, segmented, incisions sharp; segments opposite or alternate, acute, more or less concave in the upper margin, convex in the lower,*

*upper ones longer, with the uppermost shortened, lower ones shorter and triangular with the upper margin straight, veins dense, simple, parallel, equal, rising at right angles to the rhachis.*

The leaves were petioled (fig. 1, Pl. XIII). Segments are in most cases separate from one another but sometimes a slightly contiguous at base. They may be opposite as in fig. 6, Pl. VII, or alternate as in fig. 1, Pl. XIII. They are always acutely pointed at the angle where the upper and lateral margins meet. They are generally concave in the upper margin and strongly convex in the lower, and are longer than broad; but in the upper part of the leaf, they are much broader than long (fig. 4, Pl. VII), with the upper and lower margins more parallel-sided. The lower segments are more or less triangular in shape with the upper margin straight (fig. 6, Pl. VII, and fig. 6, Pl. XII). The uppermost segments are comparatively short, as may be seen from fig. 3, Pl. VII, which represents the apical part of a leaf. Fig. 5, Pl. VII, is also such an example, while fig. 7 and 8a show segments lying intermediate between the apex and the base.

This species is very closely allied to the European Rhaetic form, *N. acuminata* Schenk (*Flora der Grenzschichten*, p. 131, pl. XXXII, fig. 1—7, XXXIII, 1.), from which, however, it is distinguished by having less acuminate segments, pierced with much denser veins (ca. 3 falling in a millimetre).

Not frequent.

Loc.—*Shinamura. Okamijō.*

## 27. Nilssonia (?)

Pl. XIII, fig. 3.

A broken leaf, about 34 mm. in breadth, with the length preserved for 60 mm, seems to have been longly-elliptical in shape to judge from its rapidly tapering state both above and below. It also

appears to have been entire-margined with a comparatively weak midrib. The leaf has been flatly pressed on to the stone, and the venation is almost wholly defaced. By a careful examination, however, it exhibits faint traces of delicate parallel veins perpendicular to the rhachis; and as the blade seems to lie upon the rhachis, our specimen is probably referable to *Nilssonia*. A positive determination however must be postponed until better specimens are discovered.

### 3. *Dioonites Bornem.*

#### 28. *Dioonites Kotoei m.*

Pl. VII, fig. 1a, b, c, 1e. Pl. XIV, fig. 14.

*Leaf pinnated; segments opposite or alternate, lightly curved and more or less directed forward, long, linear-lanceolate, acute, inserted on the rhachis with the whole base; veins fine, equal, parallel, 7-14 in number.*

Segments of this species vary much in length and breadth, but are commonly 7-9 times as long as broad, and broadest at base. The longest segment in our specimens measures  $4\frac{1}{2}$  mm. in breadth and 33 mm. in length, with apex a little broken off. The segments are in most cases quite separate from one another; but sometimes a little contiguous. Their directions are not always the same, some being directed more acutely forward than others, some being tolerably falcate in shape, while others are more straight. Veins are delicate, and rise perpendicular to the rhachis (fig. 1e enlarged).

Very closely akin to *Dioonites Brongniarti Schenk* (*Flora der nordwestdeutsch. Wealdenform.*, p. 336, pl. XXXII, fig. 2, 2a) from the Wealden of Germany, from which however the Japanese form is distinguished in having longer segments traversed by a greater number of veins (in *D. Brongniarti*, 5-6). Our fossil may also be com-

pared to the Gristhorpe forms such as *D. medianus* Bean and *D. angustifolius* Bean (Leckenby, *Proc. Geol. Soc.*, vol. XX, 1864, p. 77, pl. VIII, fig. 2 and 3), the first of which however has shorter, and the second, more straight and gradually sharpening segments.

Rather rare.

Loc.—*Shinamura, Tanimura.*

#### 4. *Zamites* Brgt.

##### 29. *Zamites parvifolius* Geyl.

*Zamites parvifolius*—Geyler, Ueber foss. Pflanz. a. d. Juraform. Japans, p. 227, pl. XXXII, fig. 2a. Zigno, Flora Foss. Form. Oolith., II, p. 57.

I have not been able to find any specimen that can be referable to this species.

#### 5. *Podozamites* Fr. Braun.

##### 30. *Podozamites lanceolatus* Lindl. et Hutt. sp.

*Podozamites lanceolatus*—Geyler, Ueber foss. Pflanz. a. d. Juraform. Japans, p. 228, pl. XXXII, fig. 1, 4, XXXIII, 1–3, 4b, XXXIV, 3a, 5b. Heer, Beitr. z. Juraflora Ostsib. u. d. Amurl., 1876, p. 45, pl. I, fig. 3a, p. 106, XXIII, 1c, 4a, b, c, XXVI, fig. 2–10, XXVII, 1–8. Beitr. 1878, p. 6, p. 20, pl. V, fig. 1–11. Beiträge zur foss. Flora Spitzbergens. p. 35, pl. VII, fig. 1–7 c, d. Schmalhausen, Beitr. zur Juraflora Russl., p. 29, pl. V, fig. 3, 4, 5c. Schenk, in Richthofen's China, vol. IV, p. 248, pl. XLIX, fig. 4, 5, p. 251, I, 1–6, p. 255, LI, 3, LII, 8, p. 258, LI, 7, p. 261, LIV, 2c. Feismantel, Foss. Flora of Jabalpur Group, p. 11, pl. III, fig. 4–7, IV, 1–10.

This well known species is very widely spread in the Jurassic flora, being known from Yorkshire, Spitzbergen, Russia, Siberia,



Mongolia, China, India, Persia and Tongking. From the Rhaetic it has been described under the name of *Podozamites distans*. In Japan it occurs in great abundance and can be distinguished into the following varieties :—

a.) *P. lanceolatus* var. *genuina* Heer.

Pl. IV, fig. 2. Pl. VII, fig. 8b. Pl. XIV, fig. 12b ?

This variety is distinguished by having long narrow leaflets, each of which is drawn out into an acuminate apex.

The leaflets of this variety are frequently met with at *Shimamura* and *Okamigō*. Fig. 2, Pl. IV, has the upper part of the leaflet strongly falcate, is about 50 mm. long and 9 mm. broad, and is furnished with about 25 fine longitudinal veins. Fig. 8b, Pl. VII, has the apical end broken off; but, to judge from its superiorly gradually narrowing form, it is evident that it has terminated in an acuminate apex. It measures 5·5 mm. in breadth, and has about 27 veins. Fig. 12b, Pl. XIV, from Hakogase is a doubtful case, but its general form points more to this than to any other variety. It possesses 25 veins, and is 5·5 mm. broad near the base.

b.) *P. lanceolatus* var. *intermedia* Heer.

Pl. IV, fig. 3a, 4a. Pl. V, fig. 3, 7, 9.

Leaflets in this variety are gradually narrowed towards the apex which is bluntly pointed.

Specimens are by no means rare at *Shimamura* and *Okamigō*, but those from the former locality are alone figured here. Fig. 3, Pl. IV, which is the longest of the specimens with both apex and base preserved, measures 83 mm. in length and 12·5 mm. in breadth; fig. 4a, which is shorter, is 55 mm. long and 14–15 mm. broad, whilst fig.

3, Pl. V is 57 mm. by 10·5 mm. Fig. 7 and 9, Pl. V, represent leaflets which seem to have been longer when compared with the above three, and are indeed the typical specimens of this variety, the shorter ones representing what may be considered as passage forms between this and the succeeding group. Veins vary between 20 and 25 in number.

c.) *P. lanceolatus* var. *Eichwaldi* Heer.

Pl. IV, fig. 1a, 4b, c. Pl. V, fig. 2, 4, 5a, b, c, 6.

Pl. XI, fig. 6.?

Leaflets are more or less parallel-sided, with apex obtuse or nearly rounded.

As in Bureja, China and Spitzbergen, this is the most frequent of all the varieties of *P. lanceolatus* occurring in Japan. The specimens I have figured vary considerably in size and breadth, some being much smaller and some much longer than others. Smaller forms are represented in fig. 1, 4, Pl. IV, and fig. 5, Pl. V, of which the last is perhaps the smallest that has as yet been figured, though not completely preserved. Fig. 4, Pl. V, is a broader form and corresponds to the typical figures of Heer (comp. Beitr. 1876. pl. XXVII, fig. 1). So is fig. 6. Fig. 26, Pl. V, seems to have been considerably longer than others; but as it has the sides nearly parallel and the apex blunt, it must be referred to this variety. A leaflet (Pl. V, fig. 2a) which I formerly considered as *Podozamites pulchellus* Hr. (Bull. Geol. Sec. Japan, B. Vol. I, p. 6) is probably an abnormal form of *P. lanceolatus Eichwaldi*, as it seems to have been furnished with a short stalk. So is the leaflet from Ushimaru (Pl. XI, fig. 6) with 25 veins and mentioned in the *Bulletin* as a new species.

Found at *Shimamura*, *Okamigō*, *Tanimura* and *Ushimaru*.

d.) *P. lanceolatus* var. *minor* Heer.

Pl. V, fig. 8.

A single specimen with three leaflets attached to a rhachis was obtained at *Shimamura*. These leaflets are narrowly lanceolate with acute apex and with about 18 veins. Heer says of his variety *minor*, that the leaflets are narrow, linear-lanceolate with sharply pointed apex and with 14–16 veins (*Beitr.* 1876, p. 110). To this our specimen must be referred, so like is it to the figures of Heer (*Beitr.* 1876, pl. XXVII, fig. 7, 8), although in number of veins it slightly exceeds the Siberian.

A leaflet on the right hand side of our drawing is very unfavourably situated. It looks narrower than it actually is. It measures about 6.5 mm. in breadth, and is not at all narrower than others which also possess a nearly equal breadth.

e.) *P. lanceolatus* var. *latifolia* Heer.

Pl. IV, fig. 1c. Pl. V, fig. 1. Pl. VI, fig. 1.

This variety is distinguished by having larger, longly-oval, obtuse leaflets with 20–30 veins.

The specimens, though all incomplete, I cannot but identify with this variety. Fig. 1c, Pl. IV, which is wanting both at apex and base, measures 20 mm. in breadth, and is pierced with about 30 veins. Fig. 1, Pl. V, shows two leaflets, one with the apex and the other with the base. These leaflets agree in form with those figured by Heer from Spitzbergen (*Beitr.* 3. *Foss. Flora Spitzb.*, pl. VIII, fig. 3). Veins are very numerous—about 30 in number—and the breadth in the broadest part of the blade is 19 mm. Fig. 1, Pl. VI has 28 veins and is 17 mm. broad.

Specimens were obtained at *Shimamura* where they seem to have been rather rare.

f.) *P. lanceolatus* var. *brevis* *Schenk*.

Pl. XII, fig. 18.

Leaflets small, longly oval; apex acute; veins fine, about 20 in number.

A specimen from Okanigō is longly-oval in shape, 30 mm. long and 11 mm. broad with the broadest part near the middle of the leaflet. It is pointed at apex, and possessed of about 20 delicate veins. It agrees very well in general form with one figured by Schenk (*Richthofen's China*, vol. IV, p. 251, pl. L, fig. 1) from Patatshu, west of Peking in China, though ours is somewhat longer.

g.) *P. lanceolatus* var.

Pl. V, fig. 5d.

Leaflets small, abruptly narrowed above and ending in acute apex.

A leaflet which I have here separated from others is very small when compared with the leaflets of other varieties. It corresponds in size to the smallest form of *P. lanceolatus Eichwaldi* already alluded to (Pl. V, fig. 5), from which it differs in having the blade quickly narrowing above and ending in pointed apex. It is 24 mm. long and 6 mm. broad, and possesses about 20 fine veins. It may be a young leaflet belonging to one of the many varieties of *P. lanceolatus*, which however is very difficult to determine.

31. *Podozamites tenuistriatus* *Geyl.*

Pl. XII, fig. 19.

Leaflets lanceolate, gradually attenuated above, suddenly narrowed at base, acute; veins fine, 14–16 in number; interstitial veinlets very fine.

*Podozamites tenuistriatus*—Geyler, Ueber foss. Pflanz. a. d. Juraform. Japans, p. 228, pl. XXXII, fig. 2 b.

Dr. Geyler established this species on a leaflet from the Tetorigawa-valley, which was 50 mm. long and 10 mm. broad, and pierced with 14–16 fine veins. The only specimen which I could obtain of this species is a leaflet from Okamigō, 32 mm. long and 10 mm. broad, therefore somewhat shorter than the one figured by Geyler. It is furnished with about 15 very faint delicate veins between which I have often observed one or two extremely fine veinlets. Its form is lanceolate with the broadest part near the base, and above gradually narrowing into a rather acute apex. *Podoz. ensiformis* Hr., with which Geyler compares this species, has much slenderer leaflets pierced with a somewhat less number of coarser veins.

I may here advance my opinion concerning the fragmentary specimens of a *Podozamites* identified with *P. ensiformis* Hr. by Geyler (*Foss. Pflanzen*, p. 227, pl. XXXII, fig. 1). This author gives for his specimens 20–22 veins, whilst Heer's species possesses only 10–13 (*Beitr.* 1876, p. 46); and he rejects *Zamites Schmidtii* Andr. from the Liassic flora of Steierdorf for the very reason that the latter has 14–16 veins. Here evidently Dr. Geyler is mistaken; and this mistake has been noticed by Heer (*Nachtr.* p. 3) who considers the Japanese specimens as referable to *P. tenuistriatus* Geyl. But, as already mentioned, they possess 20–22 veins, whilst leaflets of *P. tenuistriatus* have only 14–16, only a little more than in *P. ensiformis*. Therefore I think it most proper to refer the specimens described by Dr. Geyler as *P. ensiformis* Hr. to *P. lanceolatus* var. *genuina* Hr., to which indeed his broken leaflets show the greatest resemblance. Loc.—Okamigō.

### 32. *Podozamites Reinii* Geyl.

Pl. III, fig. 6a b c. Pl. IV, 1b, 3b. Pl. VI, fig. 2, 3b c d, 4–7,  
8a b c e. Pl. IX, fig. 12a. Pl. XII, fig. 4.

Leaflets alternate, distant, more or less directed forward, ovate,

oblong, or nearly round, obtuse at apex, unequal at base, shortly petioled; veins numerous, simple, parallel, 34–50 in number; interstitial veins very fine.

*Podozamites-Reinii* Geyler, Ueber foss. Pflanz. a. d. Juraform. Japans, p. 229–230, pl. XXXIII, fig. 4a, XXXIV, 1, 2, 5a, XXXIV, 3 b, 4.

Leaflets of this Japanese species of *Podozamites* are very plentifully found at Shimamura and Okamigō, where they show great diversities in shape, which however are, I believe, to be considered merely as a variability so frequent among the leaves of cycads. On this account I do not adopt the varietal names of *latifolia* and *angustifolia* proposed by Dr. Geyler.

The shape of the leaflet is either ovate (e. g. fig. 2, 6, Pl. VI), or oblong (e. g. fig. 3b, Pl. IV, fig. 3c, 7a, Pl. VI) which often approaches to elliptical (e. g. fig. 7b, Pl. IV, fig. 8c, Pl. VI, fig. 12a, Pl. IX). Between these forms there are all sorts of gradations from one to the other.

A small round leaflet represented in fig. 4, Pl. XII, 11–12 mm. in diameter and with very fine veins a little over 30 in number is, I believe, an abnormal form of this species.

The base of the leaflet is either subcordate (Pl. III, fig. 6a, Pl. VI, fig. 2, 4, 6), or it passes gradually into a petiole without leaving any indentation on either side of it (Pl. III, fig. 6c, Pl. IV, fig. 1b).

It is to be noticed here that in all of the leaflets of this species interstitial veins are in most cases distinctly observable, generally one (fig. 6e, Pl. III), but sometimes two between the principal ones; and that in all of them the two sides of the base are more or less unsymmetrically formed, as may be seen most prominently in fig. 6c, Pl. III, fig. 3b, Pl. IV and fig. 3b, 3d, Pl. IV.

Loc.—*Shimamura, Ozō, Yanagidani, Tanimura, Okamigo.*

33. *Podozamites* sp.

Pl. XII, fig. 12.

This is an imperfect specimen which is wanting both at apex and base. It is attached to a stone in a curved state. It is 3 mm. broad, and may have been long drawn out at apex. Veins are distinct, about 8 in number with a finer one between.

The leaflet is probably referable to *Podozamites*, and indeed I mentioned it in the *Bulletin* as a new species. But now I consider it better to be designated with a simple name of *Podozamites* sp., as the specimen is not complete enough for exact determination.

Loc.—*Okamigō*.34. *Podozamites* sp.

Pl. VII, fig. 9.

A leaflet longly elliptical in form, obtuse at apex, nearly sessile at base, and furnished with 12 rather distant parallel veins. It measures 30 mm. long and 12 mm. in breadth, and resembles much the narrower forms of *P. pulchellus* Heer (*Beitr. z. foss. Flora Spitzb.*, p. 38, pl. IX, fig. 10–14), from which however our specimen seems to differ in possessing 5–10 very fine dense interstitial veins. Whether Heer's species may have so many veinlets as in ours is a question which can only be settled after the discovery of a much greater number of specimens.

Loc.—*Simamura*.6. *Dictyozamites* Oldham.

“Leaflets many-veined, subauriculate at base: veins dichotomous, reticulated.” (Oldham.)

Oldham and Morris had described in their *Rajmatal Flora* a very interesting plant which then accorded most with the genus *Dictyopteris* Gubier of the Carboniferous System, and therefore called by them

*Dictyopteris falcata*. Oldham, however, who had at first followed the opinion of his colleague afterwards came to the conclusion, that the plant in question is not a fern, as at first appeared, but a cycad near to the genus *Otozamites* Br. His reasons were :

Firstly, that the Indian leaflets possess not the slightest trace of a midrib which in *Dictyopteris* is present as a "quasi-midrib or bifid midrib," from which "all the veins of the fronds diverge in a flabellate or radiated form," while in the former "the strong nerves pass out parallel to each other from the base of the leaf, and proceed towards the apex in nearly right lines interrupted only by the anastomosing or reticulating cross nerves, which pass from one to the other: the areolae thus become subquadrangular, not hexagonal."

Secondly, that the texture of the leaflets is coriaceous.

Thirdly, that the equal leaflets are regularly disposed along a rachis which is provided with a terminal leaflet.

And then he proposed for the Indian plant the new generic name of *Dictyozamites*.

Dr. Stur of Vienna also came to the same conclusion by examining the figures of this plant.

The above view of these two eminent men has also been adopted by Dr. Feistmantel who fully treats of this subject in his "*Italischen Cycadeengattungen Ptilophyllum and Dictyozamites*" (p. 17).

I possess a set of leaflets from Kaga and Hida, which I treat under the name of

### 35. *Dictyozamites indicus* Feistm. var. *distans* n.

Pl. X, fig. 4-10. Pl. XI, fig. 5.

*Leaf simple, elongated; leaflets either short and blunt, or long, falciform, and acute at apex; attached to the rachis with the middle of the base which is either very shortly petioled or quite sessile and*



distant from one another; corners of the base distinctly auriculate; leaf terminated by a single leaflet; veins numerous, fine, rising at base, and radiating and anastomosing; thus forming nets which are long and sub-parallel in the middle of the leaflet, shorter and polygonal towards the apex and the margin.

*Dictyozamites indicus*—Feistmantel, Jurassic Flora of the Rajmahal Group, in the Rajmahal Hills, p. 70, pl. XLVI, fig. 7, 8. Jurassic Flora of the Rajmahal Group from Golapili, p. 180, pl. II, 5, 6. Ueber die indischen Cycadeengattungen *Ptilophyllum* Morris und *Dictyozamites* Oldham, p. 18, pl. IV, fig. 7, 7a, 8, pl. V, fig. 1–4, pl. VI.

*Dictyopteris falcata* and *Dictyopteris falcata* var. *obtusifolia*—Oldham and Morris, The Fossil Flora of the Rajmahal Series, Rajmahal Hills, Bengal, p. 38, pl. XXIV, fig. 1, 1a, pl. XXIV, fig. 2, 2a.

This species is greatly variable in the form of the leaflets. Feistmantel had already united Morris' species and variety. The distinguishing characters are the ending of the leaf at apex, the mode of attachment of the leaflets to the rhachis, the basal ears, and the reticulation of fine veins. The first two of these characters are unfortunately not to be seen in our specimens, as most of them occur in an isolated state. A single specimen was obtained with the rhachis preserved, but the preservation is such that the important character of the attachment of the leaflets is not distinctly observable. The basal ears are very distinct in fig. 4, 5a, 6, 8 and 9. The leaflets are more or less oblique with upper part often curved to one side. Fig. 5, Pl. X, represents a leaflet which has the apical portion most strongly falcate. Fig. 7 shows one with obtuse apex, which corresponds to Feistmantel's 'short and blunt' while fig. 5, 8, and 10 represent his 'long and falciform' leaflets. These latter are all more or less sharp at apex, and fig. 10 may indeed be said to possess an acuminate apex.

Most of our leaflets seem to have been sessile, as we see no in-

dication of a stalk except in fig. 8, which shows a short but distinct one.

The mode of venation is exactly as Feistmantel describes and figures. Fine, equal, numerous veins proceed from the base to the apex and margin of the leaflet, in such a way as to form long and narrow nets along its median line, and shorter and polygonal ones around its periphery.

Agreeing in all of the above mentioned characters, our plant is distinguished from the Indian one in having the leaflets not so closely set along the rachis as in the latter. On this account I think it better to raise it to a distinct variety (see fig. 4).

This species is said to be highly characteristic of the Rajmahal Group in India. Its discovery therefore in the Jurassic system of Japan is especially noteworthy, as at Ozō it has been found associated on the one hand with a *Sagenopteris* closely akin to *S. rhoifolia* Presl. and on the other with the common Oolitic types such as *Asplenium argutulum*, *A. distans*, and *Onychiopsis elongata*.

This is the most numerous fossil at Ozō, where it takes the place of *Podozamites lanceolatus* of other localities, of which indeed not the least trace is here to be found. Rarer at Ushimaru.

Loc.—Ozō, Ushimaru.

### 36. *Dictyozamites grossinervis* n.

Pl. VII, fig. 10.

*Leaflets longly ovate, very shortly petioled at the middle of the base; basal corners subauriculate; veins equal, coarse, rising at the base of the leaflet and radiating, forming elongated nets which are longer in the middle and shorter towards the apex and margin of the leaflet.*

This species is closely akin to the preceding, in fact agreeing with it in the general form of the leaflets, their mode of attachment to the

rhachis, the auriculation of the basal corners, and in the general mode of venation, but is decidedly distinguished in having a less number of coarser veins with a correspondingly less number of nets, and in having the leaflets set more closely together. Feistmantel indeed figures leaflets which show a small number of areoles (*c. g. Cycadeen-gattungen*, pl. IV, fig. 7, VI, 4); but all of these pertain to much smaller forms. Our specimen shows larger leaflets with few nets. Therefore it is quite unsafe even to create a variety out of our specimen, the number and size of veins being considered as very important characters in the discrimination of fossil plants. However, there is no doubt that our plant is very nearly related to *Dictyozamites indicus*, and I regard it as belonging to the same genus.

Our specimen is very meagre. The apices of the leaflets could not be well exposed, therefore it is very difficult to decide whether they ended acute or obtuse.

Very rare.

Loc.—*Shimamura*.

## Fam. 2. Cycadeae.

### 7. Cycadeospermum Sap.

#### 37. Cycadeospermum japonicum Geyl.

*Cycadeospermum japonicum*—Geyler, Ueber foss. Pflanz. a. d. Juraform. Jap., p. 231, pl. XXXIII, fig. 5.

I have not been able to find any specimen referable to this species.

## Order 2. Coniferae.

### Fam. 1. Taxaceae.

#### 1. Ginkgodium m.

*Leaf coriaceous, entire or lobed, gradually narrowed towards the base*

which is thickened at its margin and gradually passes into a short petiole. Veins numerous, simple, parallel; interstitial veins very fine.

The leaves which I am going to describe below under this genus, I brought under *Baiera* in the *Bulletin*. But now I have reason to believe that they must be treated as a distinct genus, related on one side to *Ginkgo* and on the other to *Baiera*. With the former it has in common the thickening of the lower margin of the leaf and with the latter the numerous, simple, parallel longitudinal veins. But these veins coming down directly on the thickened margin without converging, decidedly distinguish our plant from the two above named ones. This mode of venation may be compared to that of *Whittlesya* Newb. from the Coal-Flora of Pennsylvania (*Lesquereux, Descript. of the Coal-Flora of Pennsylvania, 1880, vol. I, Pl. IV*).

The discovery of this genus standing between *Ginkgo* and *Baiera* shows more strongly the close relationship existing between these genera which was first pointed by Heer (*Beitr. z. Juraflora Ostsib. u. d. Amurl., 1876, p. 51*).

### 38. *Ginkgodium Nathorsti* m.

Pl. II, fig. 4e. Pl. III, fig. 7. Pl. VIII. Pl. IX, fig. 1-10.

Pl. XII, fig. 14, 15.

*Leaf coriaceous, gradually attenuated below into a short petiole, entire or lobed; apex obtuse. Longitudinal veins dense, simple, parallel; interstitial veins very fine, simple.*

The leaves which I mentioned in the *Bulletin* (page 8) as three new species of *Baiera*, I now unite into one, as I was convinced by the examination of many specimens that an apparent diversity in the shape of the leaves is merely a variability. Some leaves are broad and more or less narrowly fan-shaped, and are nearly or quite entire (Pl.

VIII, fig. 4, Pl. IX, fig. 1, Pl. XII, fig. 15), or deeply lobed (Pl. VIII, fig. 2a, 5, 6, Pl. IX, fig. 2, Pl. XII, fig. 14). Some are quite entire and lanceolate with subparallel sides (Pl. VIII, fig. 2c, Pl. IX, fig. 9, 10). Between these forms there are all sorts of gradations, both in shape and in the depth of the central slit, just as in our recent *Ginkgo biloba*.

The lower margin of the leaf is thickened as in *Ginkgo*, but a little more strongly than in the latter. The petiole, however, is very short in comparison to the very long one of *Ginkgo*. The lower end of the petiole which is the point of attachment to the stem, is slightly expanded as is best seen in fig. 2a, Pl. VIII. and fig. 5, Pl. IX.

As to the number of veins, they vary from 20 to 40, according to the breadth of the leaf. In the lobed leaves 20–30 come in a lobe, and in the lanceolate entire ones we find 30–35. For example a leaf represented in fig. 9, Pl. IX, which is 66 mm. long and 21 mm. broad, possesses 30 veins with an equal number of interstitial veins, and that represented in fig. 2c, Pl. VIII, which is a little longer, has 35.

Fig. 11, Pl. VIII, representing a small leaf only 13 mm. in breadth, shows 23 veins.

In leaves of an oval shape (Pl. VIII, fig. 14, Pl. XII, fig. 15), the veins vary between 30 and 40.

In all of our specimens, interstitial veins are more or less distinctly observable and are always single (Pl. VIII, fig. 1a, 11a, Pl. IX, fig. 10a).

It is here to be added, that when the leaves are lobed they seem to have been always two-lobed, the apparent anomalies seen in some of the figures being only accidental.

Very numerous at Shimamura, but rarer in other localities.

Loc.—*Shimamura, Yanagidani, Okamiyō.*

## 2. *Ginkgo* Thunb.

### 39. *Ginkgo digitata* Brgt.

Pl. XIII, fig. 2.

Leaf semicircular, entire or with two to six lobes, petioled; petiole long, slender, canaliculated above; veins numerous, repeatedly dichotomous, flabellately divergent.

*Ginkgo digitata*—Heer, Beitr. z. foss. Flora Spitzb., p. 40 pl. X, fig. 1–6. Heer in Regel's Gartenflora, 1874, pl. 807. As *G. digitata integrinsecula* Heer, Beitr. z. foss. Flora Spitzb., p. 44, pl. X, fig. 7–9. Beitr. z. Jurafflora Ostsib. u. d. Amurl., 1878, p. 25, pl. VI, fig. 5, 6. Nachträge, p. 5.

*Baiera digitata*—Schimper, Pal. Végét., vol. I, p. 423.

*Cyclopteris digitata*—Brgt., Végét. foss. I, p. 239, pl. 61, fig. 2, 3. Zigno, Flora Foss. Form. Oolith., I, p. 102.

A leaf of this species in an excellent state of preservation was procured from Okamigō. It measures 30 mm. in length and 52 mm. in breadth. It is fan-like in shape, and furnished with three comparatively shallow clefts on the top, one of which is nearly in the middle of the leaf and attains the depth of one-third of its length. The other two are on each side of the central one and are much nearer to it than to the lateral margins of the leaf. They are about one-half as deep as the central one. Veins are very distinct, all of them diverging from the base of the leaf and ending in its upper extremity, after having repeatedly forked on their way.

The Japanese specimen, according to the descriptions of Heer, must belong to his variety *quadriloba* (Foss. Flora Spitzb., p. Pl. X, fig. 3a), although the central incision is much shallower than in the one figured by that author.

Heer described in his contributions to the Spitzbergen and Sibe-

rian floras closely allied, nearly entire-margined leaves as *Ginkgo integrifolia* Hr. But this species he afterwards placed under *G. digitata* as a variety only (Nachtr. p. 5), as Prof. Nathorst discovered in the Oolite of Scarborough specimens which show passage forms between these two species.

Seems to have been very scarce in Japan. Loc.—*Okamigō*.

#### 40. *Ginkgo* cf. *lepidus* Heer.

Pl. XIV, fig. 10.

*Ginkgo lepidus*—Heer, Beitr. z. Juraflora Ostsib. u. d. Amurl., 1876, p. 62, pl. XII, pl. VII, fig. 7. Nachtr., p. 17, pl. IV, fig. 7b, 9–12, pl. V, fig. 1a, 2, 3a, 4.

A leaf which I figure here is not very complete. It is divided into four lobes, and therefore furnished with three slits, the central of which is the deepest, nearly reaching to the base of the leaf whence it goes off into a petiole. The petiole however is unfortunately not preserved. The other two slits are shallower. The lobes are narrow, parallel-sided and acute at apex, as is seen from one of them. Veins are parallel to the sides and about 6 in a lobe. Judging from these characters, our plant is probably referable to the above named species of Heer, which is distinguished from the very nearly related *G. sibirica* Hr. in possessing narrower and especially acute lobes.

Very rare.

Loc.—*Hakogase*.

#### 41. *Ginkgo sibirica* Heer.

*Ginkgo sibirica*—Geyler, Ueber foss. Pflanz. a. d. Juraform. Japans, p. 231, pl. XXXII, fig. 6. Heer, Beitr. z. Juraflora Ostsib. u. d. Amurl., 1876, p. 61, pl. VII, fig. 6, IX, 5b, XI, p. 116, pl. XX, fig. 3b, 6c, XXII, 3. Beitr. 1878, p. 25, pl. VI, fig. 8a b. Nachtr. p. 16, pl. IV, fig. 13, V, 5–8. Schmalhausen, Beitr. z. Juraflora Russl., p. 34.

I have not been able to find any specimen undoubtedly referable to this species.

### 3. *Czekanowskia* Heer.

This genus is doubtfully represented in Japan, and only by fragments which most approximate to

#### 42. *Czekanowskia rigida* Heer (?)

Pl. XII, fig. 11. Pl. XIII, fig. 10.

An indistinct specimen from Ozō (fig. 10, Pl. XIII) has linear leaves about 1 mm. broad, which dichotomize and are in some cases seen with a distinct median vein. Leaves on the right-hand side of the stone appear as if fasciculated. Fig. 11, Pl. XII, shows a single leaf 1 mm. broad, and once forked with a distinct canal running through the lobes. From these characters our fragments seem to be referable to the above denominated species which is found in Siberia, China, Russia and England, and also in the Rhaetic of Sweden. (Comp. Heer's *Beiträge z. Juraflora Ostsib. u. d. Amurl.*, 1876, p. 70, Pl. V, fig. 8–10, Pl. VI, 7, X, 2a, etc. *Beitr.* 1878, p. 7, Pl. I, fig. 16, p. 76, Pl. IV, fig. 3b c. Schenk in Riechthofen's *China*, vol. IV, p. 251, Pl. L, fig. 7, p. 262, Pl. LIV, fig. 2a. Schmalhaus-sen's *Beitr. z. Juraflora Russl.* p. 36, Pl. V, fig. 2e, 6a, 7, etc.).

Loc.—Ozō, *Okamigō*.

### 4. *Taxites* Brogt.

#### 43. *Taxites* sp.

Pl. X, fig. 15–19. Pl. XII, fig. 16, 17.

The leaflets in the above cited figures all belong, I believe, to one and the same species. They are linear-lanceolate, 10–15 mm. long and 2.5–3 mm. broad, obtusely pointed at apex and constricted at base, with a weak midrib. In form they remind us of many of the so-called *Cycadites*, e. g. such as *C. zumioides* Leckenby (*Proc. Geol.*



*Soc.*, 1864, vol. XX, p. 77, Pl. VIII, fig. 1) and C. Saladini Zeiller (*Examen de la Flore Fossile des Couches de Charb. du Tonking*, p. 322, Pl. XI, fig. 8, 9, 10 A, Pl. XII, fig. 8, 8 A, 9, 9 A, 10). But the former seems to have had much more linear leaflets with a stronger midrib, and the latter is said to have had a cordate base. Our plant may be most closely allied to *Taxites brevifolius* Nath.\* from the Oolite of England whose original specimens I had an opportunity to examine at Stockholm.

In the *Bulletin* I mentioned the leaflets now under consideration as a new species of *Cycadites*. But as Prof. Nathorst believes them to be undoubtedly the remains of a conifer, and as they occur only in an isolated state, I now satisfy myself by calling it simply *Taxites* sp.

Loc.—Ozō, Okamigō.

#### 44. *Taxites* sp.

Pl. VI, fig. 3a.

Two fragments of linear leaves, 2–3.5 mm. broad, gradually narrowed above and furnished with a distinct evanescent midrib, on both sides of which are seen fine longitudinal striae. I mentioned them in the *Bulletin* as belonging to *Cycadites gramineus* Hr. (?). But now I take the opportunity of bringing them under *Taxites* like the preceding species, and indeed very near to *T. longifolius* Nath. occurring in the Rhaetic formation of Schonen in Sweden.

Loc.—Shimamura.

### Fam. 2. Abietaceae.

#### 5. *Pinus* L.

##### 45. *Pinus* cf. *prodromus* Heer.

Pl. XII, fig. 3.

*Pinus prodromus*—Heer, Beitr. z. foss. Flora Spitzb., p. 44, pl. VII,

\*Nathorst, *Berättelse, afgifven till Kongl. Vetenskaps-Akademien, om en med understöd af allmänna medel utförd vetenskapliga resa till England*, p. 73

fig. 7a, X, 11-14. Nachträge z. Juraflora Sibir., p. 27, pl. VII, fig. 12c.

Many linear leaves mostly 1 mm. in breadth, but sometimes a little broader, are found with a strong midrib, on both sides of which we can often observe fine longitudinal striae. Though they are always found scattered and only in fragments, I believe they are to be identified with the species discovered in Spitzbergen and Siberia.

A fragment of a leaf of this species is also found by the side of *Adiantites Heerianus*. (Fig. 2, Pl. XII). Loc.—*Shimamura, Tanimura*.

#### 46. *Pinus Nordenskjoldi* Heer.

Pl. IX, fig. 12b.

*Cyclopitys Nordenskjoldi*—Yokoyama, Bull. Geol. Soc. Japan, Part B, vol. I, No. 1, p. 8. ?

(?) *Cyclopitys Nordenskjoldi*—Schmalhausen, Beitr. z. Juraflora Russlands, p. 40. Nachträge zur Juraflora d. Kohlenbassins von Kuznesk am Altai, pl. I, fig. 1.

*Pinus Nordenskjoldi*—Heer, Beitr. z. foss. Flora Spitzb., p. 45, pl. IX, fig. 1-6. Beitr. z. Juraflora Ostsib. u. d. Amurl., 1876, p. 76, pl. IV, fig. 8e, p. 117, pl. XXII, fig. 4a, b, XXVII, 9a, XXVIII, 4. Beitr. 1878, p. 26, pl. II, fig. 7-10. Nachtr., p. 28, pl. I, 8b, 6b, IX, 36.

Long linear acuminate leaves, 2-2.5 mm. in breadth, thick in texture and scattered on a stone, agree very well with those described under the above name from Spitzbergen and Siberia. The central vein is tolerably thick, and through a magnifier we can observe in some leaves 3-4 finer longitudinal parallel veins, a fact which was also noticed by Heer (*Beitr. 1876, p. 117. Pl. XXVIII, fig. 4c*).

Dr. Schmalhausen identifies the isolated leaves described by Heer as belonging to a pine with his *Cyclopitys Nordenskjoldi* in which the

needle-shaped leaves are arranged in whorls as in our recent *Sciadopitys*. In the *Bulletin* I followed the above author in the generic denomination of our species. But in reverence to Prof. Nathorst of Stockholm who thinks it still unsettled whether the plants described by Heer and Schmalhausen really belong to one and the same species, I resume the older denomination of Heer. Loc.—*Shinamura*.

## 6. *Palissya* Endl.

Species of this genus are mainly known from the Rhaetic and Lower-Liassic beds of Europe, but also from the Rajmahal, Jabalpur and Kach series in India.

### 47. *Palissya* sp.

Pl. IX, fig. 11.

A single specimen of a branch of a coniferous tree belonging to the family of Abietaceae shows linear-lanceolate leaves, 10–11 mm. long and  $1\frac{1}{2}$  mm. broad, constricted at base and decurrent to the stem. Each of these leaves is pierced with an indistinct midrib.

This species is undoubtedly very closely akin to *P. jabalpurensis* Feistm. (*Flora of the Jabalpur Group*, p. 16, Pl. IX, fig. 1) from the Oolite of India. It is also not unlike a *Palissya* figured by Feistmantel, and described as closely related to *P. indica* Feistm. (*Jurassic Flora of the Rajmahal Group*, Pl. XLV, fig. 9) from the Liassic series of the same country. To our great regret the Japanese specimen has the apex of all the leaves broken, and so it does not allow us to institute a stricter comparison with the above fossils.

Loc.—*Shinamura*.

## Incertae Sedis.

### 48. *Vallisneriites jurassicus* Heer. (?)

Pl. III, fig. 8. Pl. XIII, fig. 5–8.

Fragments of very long parallel-sided leaves,  $2\frac{1}{2}$ –5 mm. in

breadth, resemble very much those described by Heer under the above name from Ust-Balei in Eastern Siberia (Beitr. z. Juraflora Ostsib. u. d. Amurl., 1878, p. 8, Pl. I, fig. 22-27). It is very much to be regretted that in nearly all of our specimens, the surface of the leaf has become entirely smooth, and even in some in which we can trace very faint delicate longitudinal striae, these striae are by no means so distinct as in the Siberian specimens.

Fig. 8, Pl. III. represents the longest leaf among our specimens. It is complete at one end, but broken at the other. Its length is 150 mm. and breadth 3.5-4.5 mm.

I obtained only one specimen from *Shimamura*, but a good many from *Ozō*.

#### 49. *Carpolithes ginkgoides m.*

Pl. X. fig. 20-23.

*Fruit ovate, sharply edged, rounded at base, sharply beaked at apex.*

There occur many small ovate bodies in the black shale of *Ozō*, which are furnished with a sharp beak at the apex. This beak in one specimen (fig. 22) is very long drawn out. The length of these bodies is 7-11 mm. and the breadth 3.5-4.5 mm. They are all provided with a sharp longitudinal edge which is very distinct in fig. 20 and 23. Their surface, when examined through a magnifier, reveals delicate longitudinal striae.

These are perhaps nuts of *Ginkgo*, like those of Eastern Siberia, considered by Heer as belonging to *G. Sibirica* Heer (Beitr. z. Juraflora Ostsib. u. d. Amurl., p. 58, Pl. XI, fig. 13-16). Our specimens look most like fig. 13 of Heer; however they are all much narrower in form than those of Siberia.

Loc.—*Ozō*.



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# On Pyroxenic Components in certain Volcanic Rocks from Bonin Island

by

Yasushi Kikuchi.

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With Plate XIV *bis*.

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The following account of the Pyroxenic components in the rocks of Bonin Island is based upon the investigation of materials collected by myself, during a short visit to that island in November, 1887.

Ogasawarajima or Bonin Island is the name applied to an island-group of volcanic origin, apparently forming part of the chain of of volcanoes which extends from Central Japan through the *Shichitō Group* of the Prov. Izu. The most important of the Bonin Island-Group is that known as Chichijima (Peel Island, Lat.  $27^{\circ} 5' N.$ , Long.  $142^{\circ} 15' E.$  Green.) It has a spacious harbour known as Futanikō (Port Lloyd) which without very good foundation has been regarded as the relic of a volcanic crater. The geological collections were principally made in this island, and also a few in Hahajima (Coffin Island) which is situated about 20 geogr. miles S.S.W. of Chichijima.

The volcanic activities seem to have subsided long since in these islands, and consequently their general features differ from those of such islands of the *Shichitō* or *Volcano Group* which have active volcanic cones. The interior is in some places covered with dense tropical forest, among which rise numerous pointed

pinnacles and ridges, due to the extrusion of the harder rock-masses by erosion. The most prominent of these ridges rises about 1100 ft. above sea-level.

The volcanic rocks are chiefly Andesite ; sometimes in a massive state, occasionally showing prismatic joints ; sometimes interstratified with tuffs. These tuffs usually contain fragments of volcanic rock, of various sizes, forming agglomerates. The volcanic rocks are generally much altered, and as the product of alteration, we find secretions of Chalcedony, Calcite, and Zeolite among the fissures. This is especially the case among the more basic glassy varieties, the characteristics of which will be given briefly in this place. They are also much decomposed at the surface into a peculiar reddish soil resembling Laterite.

In the first account relating to the geology of the island, found in the narrative of the famous American Expedition under Commodore Perry,\* it is stated (Vol. I, p. 202) "The geological formation of the island is trappean, with its various configurations and mineralogical peculiarities ; columnar basalt appears, and hornblende and chalcedony are found." The 'hornblende' mentioned in the above citation most probably refers to the crystallized *Rhombic Pyroxene* here to be described. This mineral therefore seems to have attracted the attention of early observers. Also in some Japanese book, treating of the products of the island, we find its crystal-form figured and mentioned as Olivine, and stated as also occurring in Kitajima, a small island to the north of Ototojima.

In the summer of 1884, Mr. T. Suzuki of the Geological Survey visited Chichijima, and made a collection of rocks, an account

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\* Narrative of the Expedition of an American Squadron to the China Seas and Japan performed in the years 1852, 1853, and 1854, under the command of Commodore Perry, compiled by F. L. Hawks. 3 vol. 1 Atlas. Washington 1856.

of which was given in the Bulletin\* of the Geological Society of Japan. His collection besides contains specimens from the neighbouring island of Ototojima (Stapleton Island). A part of his collection he kindly placed at my disposal to supplement my own. The kinds of rocks from Chichijima and Ototojima, as enumerated by Mr. Suzuki are as follows :—1) Augite-andesite, 2) Augite-andesite glass, 3) Quartz Augite-andesite, and 4) Basalt. It may be noticed however, that the 'Augite-andesite glass' represents basic glasses, of the nature of Basalt-glass like Tachylyte. The absence of Olivine in these glasses is quite peculiar and noteworthy, its place being taken by the Rhombic Pyroxene and Augite.

In Chichijima, where I had the best opportunity for observing general geological features, volcanic rocks occur either in a massive state probably consolidated from lava-flows, or as agglomerates of volcanic pebbles, associated or almost cemented with tuffs. It is usual to find among the former class, a lighter coloured, porphyritic rock, the ground-mass of which is microcrystalline, usually with small quantities of glass; the essential mineral constituents being Plagioclase, Augite, Rhombic Pyroxene and Magnetite. In fact, it resembles the Augite-andesite which is found in Honshiu. It seems to be especially well developed at Hahajima. Among the pebbles that compose the agglomerates however, we find various remarkable modifications. The peculiarity of these rocks is their basic character, with a dark coloured glass basis, in which the Pyroxenes are usually developed as Rhombic and Monoclinic forms. Their mode of occurrence suggests that they were formed as the accumulations of volcanic ejections, which were hurled away from a fluid lava, rapidly cooling on its way, and thus inducing an incipient state of crystallization. In some varieties however, the structure becomes porphyritic; the crystals of Pyroxenes,

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\* Part. B. vol. I (Japanese).



and a comparatively few crystals of Plagioclase, being developed within a partly microcrystalline groundmass. The latter consists of a brown coloured basis, containing microcrystals of Plagioclase, filiform Augite, and Magnetite. These darker rocks are probably the rocks described above as Basalt. But they differ from the usual type of Basalt in the absence of Olivine. In the more glassy varieties, Plagioclase is absent except as 'Rhombic lamellæ.' These rocks are often dark pitch-coloured glass, with numerous round vesicular cavities filled with Zeolites. Under the microscope, they are always found to be of light greyish or brownish coloured glass, in which a light green coloured Augite is developed in slender filiform crystals in innumerable thick clusters. They are often found alternating with sheets of a peculiar greenish rock, resulting from the infiltration of Chalcedony and a green fibrous chloritic mineral through its mass, which thus has the appearance of a Jasper, and exhibiting microscopically a diabasic structure. This was especially well observed near Ōmura in Chichijima.

The glassy rock mentioned above often shows a most interesting modification, in which the basis becomes more glassy and contains very sharply defined crystals of Rhombic Pyroxene. In these varieties, the glass often exhibits pearly structure under the microscope, while the specimens from Ototojima are in spheroidal masses which have the tendency to separate in concentric layers like an onion. The microscopic porphyritic components are Rhombic Pyroxene, and sometimes monoclinic Augite of a light green colour, together with a microlithic form of the same mineral, Plagioclase and some Picotite. Olivine has not been hitherto recognised. Very characteristic microscopic objects in these glasses are the 'Rhombic lamellæ' already referred to. They have been found in basic glasses of other localities. A short account of these lamellæ may be given here. They are found making gradual transition to the porphyritic crystals

of Plagioclase. Thus there seems to be much probability that they are Plagioclase, as first suggested by Penck.\* Kreutz † considers them as Anorthite. Doss ‡ also observed the gradual transition to typical Plagioclase in the Palagonitic tuffs of Haurân.

The 'Rhombic lamellæ' are especially well developed in the perlitic glass of Susaki in Chichijima, and in the spheroidal glass of Ototojima. In the latter, the edges of these plates are sometimes so thickly covered with very delicate dark filaments of Augite, as to conceal the crystal almost entirely. They are extremely thin, and there is usually no action upon polarised light. Very sharply defined faces may often be recognised on the sides of the rhomb. The angles of the rhomb measures  $52^\circ$  and  $128^\circ$ , and may be considered to be formed of the faces  $P(001)$  and  $x(10\bar{1})$ , to which the face  $y(20\bar{1})$  is sometimes added (fig. 22). In more perfect crystals, it has been observed that the one side of the rhomb is formed of two faces in place of the face  $x(10\bar{1})$ ; in such cases the crystal would probably consist of faces  $P(001)$ ,  $M(010)$ ,  $y(20\bar{1})$ ,  $o(11\bar{1})$ ,  $p(1\bar{1}\bar{1})$ ; the last two faces being in the same zone with  $x$ . Fine fissures parallel to  $P$ , probably the cleavage-fissures, are especially well developed in the specimen from Susaki. The lamellæ become broader in some cases, and the cross section exhibits twin-lamellæ of the Albite-type. The twin of the Carlsbad-type has also been observed, the most typical of which is copied in fig. 21.; the zone  $[P:M]$  running practically parallel to the zone  $[M:x]$ , so that a rhombic modification sometimes results. This characteristic is peculiarly analogous to the rhombic modification of Anorthite-twin, e. g. that of Miyakejima described by the author. §

\* Studien über lockere vulkanische Auswürflinge.—Zeitschrift, d. d. geol. Gesellft. 1878 p. 99.

† Ueber Vesuvlaven von 1881 und 1883.—Tschermak's Min. u. Petro. Mitth. 1884, p. 139.

‡ Die basaltischen Laven und Tuffen der Provinz Haurân und vom Dinet et-Tulûl in Sîrien—Tschermak's Min. u. Petro. Mitth. Bd. 7, 1886 p. 527

§ On Anorthite from Miyakejima. This Journal, vol. II, p. 31.

The direction of extinction can be measured in thicker plates, in which there is a distinct effect upon the polarised ray. On the face *M*, the direction of extinction makes  $-40^\circ$  with the edge *P*:*M*. Thus there seems to be much probability that the 'Rhombic lamellæ' are Anorthite.

All of these glassy rocks contain more or less well-defined crystals of Rhombic Pyroxene, but it is in the more glassy modifications found in patches among these rocks that the well-defined crystals of this mineral are developed at the expense of the light-green coloured filiform Augite. Such modifications have been found so far on the coasts of Tatsumiura and Miyanoura in Chichijima. The specimen obtained from Tatsumiura presents a dirty brownish green colour, resulting from the alteration of the dark glass into a product resembling 'Palagonite,' in which green translucent crystals of Rhombic Pyroxene may be picked out. The specimen from Miyanoura also presents a similar character, but the degree of alteration is much less, the vesicular cavities being chiefly lined with Zeolites.\* Microscopically examined, the glass transmits a faint greyish green colour. The glass would correspond to the 'Sideromelane' in Tachylite. The fissures and cavities are filled up with a palagonitic matter, which transmit a sulphur-yellow colour in thin sections.

The palagonitic alteration-product above mentioned is of a dirty green colour, and is made up of fibrous microcrystalline aggregates, showing a weak double refraction. When it is found filling up round pores, the periphery is often radially fibrous, so that an aggregate polarization exhibiting a dark cross is observed between crossed Nicols. Before the blowpipe, the glassy portion swells up to a great bulk and easily fuses, due to the large amount of water it

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\* One of these Zeolites is *Stilbite*, in combination of the faces,  $oP$  (001),  $\alpha P\bar{x}$  (010),  $\alpha P\bar{x}$  (100),  $P\bar{x}$  (101),  $2P$  (221); another is *Chabasite*, with characteristic striations on the rhombohedral face. There are also some fibrous crystals of an uncertain Zeolite.

contains ; but the altered portion almost resists fusion. It is found also that the latter is softer, and the specific gravity is less, than the glass. The glass and the alteration-product are scarcely attacked by hydrochloric acid.

The mineralogical composition of the rocks of Tatsumiura and of Miyanoura thus far indicated, would seem to be quite singular. It is probably to be classed as special rank among the glassy form of basaltic rocks. I am indebted to Mr. T. Suzuki, for the chemical analyses given below, of the glassy rocks of Ototojima and Miyano-ura. The analyses were undertaken by Mr. R. Fukuda of the Geological Survey.

	I	II
Si O <sub>2</sub> .....	53·18 %	54·44 %
Al <sub>2</sub> O <sub>3</sub> .....	16·18	12·90
Fe <sub>2</sub> O <sub>3</sub> .....	10·30	7·08
Ca O.....	10·12	5·12
Mg O.....	6·72	12·75
K <sub>2</sub> O.....	·35	·35
Na <sub>2</sub> O .....	1·85	2·06
loss by ignition ....	1·65	5·54
	<hr/> 100·35	<hr/> 100·24

- I. is the dark spheroidal glass of Sp. G. 2·725, already mentioned, found at Kurose in Ototojima.
- II. is the glassy portion of the rock from Miyanoura, comparatively free from the alteration-product. Sp. G. = 2·75.

The higher amount of lime in analysis I. probably points to the existence of basic Plagioclase, viz. in the form of the 'Rhombic lamellæ.' The high percentage of magnesia in II. is accounted for by the rich development of the Rhombic Pyroxene, the analysis of which is given in the sequel, while Augite is very scarce. The existence of a large quantity of water is also indicated by the large quantity of loss by ignition.

It has been pointed out by Judd and Cole \* that the Basalt-glasses are of rather rare occurrence in Europe, and that when they occur, they are always found as selvage (Saalband) of dykes, or as small fragments thrown out of volcanic vents and cooled rapidly while passing through the air, whilst in some Pacific Islands (notably in the Sandwich Islands) Basalt-glasses are found as lava-streams. It has also been observed that the glasses from these islands are more transparent in thin sections than those found in Europe. Although it is not likely that the Basalt-glasses in the Bonin Islands have flowed as lava-streams, yet they seem to be nearer to those of the Sandwich Islands, &c., since they are always lightly coloured, transmitting a greenish grey or light brownish colour. Fragments of similar rocks probably derived from lapilli, have also been dredged from the bottom of the Pacific by the *Challenger*.†

Another peculiarity of the glasses of Miyanooura and Tatsumiura, is the almost total absence of Magnetite, which seems not to have separated from the magma. Olivine is also entirely wanting; the recognisable mineral constituents being Rhombic Pyroxene and Augite, with some Picotite, which is however more generally found as enclosures within the Rhombic Pyroxene.

We shall now proceed to give the characteristics and the relation of the two Pyroxenes which are developed in these glassy rocks.

### Rhombic Pyroxene.

Owing to the incoherent character of the glassy rocks, in consequence of alteration into a palagonitic substance, the crystals of the Rhombic Pyroxene which are unaffected by alteration, can be rather

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\* On the Basalt-glass (Tachylite) of the Western Isles of Scotland—Quart. Jour. Geol. Soc. vol. XXXIX, 1883, p. 457.

† Report on the Scientific results of the Exploring Voyage of H. M. S. Challenger—Narrative of the Cruise—Vol. I, pt 2, 1885—p. 813. This occurrence is the more interesting as it seems to contain Rhombic Pyroxene.

easily obtained in a fresh state from the matrix. These crystals have a stout prismatic habitus,  $\cdot 5$ —1 cm. in the direction of the vertical axis, usually flattened along the macropinacoidal face. They are somewhat brittle. The larger crystals are dark green in colour, the smaller ones transmitting a pistachio-green colour and in still smaller crystals a light olive-green colour. The observed faces,\* when referred to the axial system of vom Rath† are as follows:

$$a = \infty P \infty \quad (100)$$

$$b = \infty P \infty \quad (010)$$

$$m = \infty P \quad (110)$$

$$e = P_{\overline{2}} \quad (212)$$

$$i = {}_2P_{\overline{2}} \quad (211)$$

The predominating faces are  $a$ ,  $b$ , and  $e$ ; the prism  $m$  truncating the edge of  $a : b$  as narrow bands. The face  $i$  is usually small (fig. 1). Thus the crystal is rather simple, being a stout prism with a very flat Pyramid  $e$ , and tabular along the Macropinacoid  $a$ . In this respect it resembles the crystal of Hypersthene (Amblystegite) from Laach volcanic bombs, described by v. Rath. (l. c.). The faces of the Pyramids  $e$ ,  $i$ , are very dull and sometimes depressed a little, while the pinacoids and the prism-faces are brighter, but usually owing to surface irregularities, they do not give a very satisfactory reflection. The following goniometric measurements were performed with a small reflecting goniometer (Füss' Wollaston model). It may here suffice to show an agreement with the corresponding angles of Hypersthene given by v. Rath (l. c. p. 530):—

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\* In the position adopted by Tschermak (e. g. Lehrbuch der Mineralogie, 2te. Aufl. p. 436) the crystal is so placed that the *acute* prism-angle is turned forward, in order to bring it into analogy with monoclinic Pyroxene. In this position, the signatures and the symbols of the faces here mentioned are respectively,  $b$  (010),  $a$  (100),  $m$  (100),  $e$  (122),  $i$  (121). Fig. 9, represents a crystal formed of the faces  $a$ ,  $b$ ,  $m$ , and  $i$  figured in this position.

† Mineralogische Mittheilungen—Ueber ein neues Mineral aus Laach.—Poggendorf. Ann. d. Physk. u. Chem. Bd. CXXXVIII, 1869, p. 529.

## v. Rath (Amblystegite)

$$e : e (212 : 2\bar{1}2) = 153^{\circ} 11' \dots\dots\dots 152^{\circ} 22 \frac{1}{2}'$$

$$e : e (212 : 212) = 121^{\circ} 12' \dots\dots\dots 121^{\circ} 8 \frac{1}{2}'$$

$$i : m (211 : 110) = 138^{\circ} 35' \dots\dots\dots 138^{\circ} 55'$$

$$a : m (100 : 110) = 136^{\circ} 5' \dots\dots\dots 135^{\circ} 50'$$

From the last value the prism-angle of the Pyroxene would become  $92^{\circ} 10'$ .

The characteristic cleavage of the prism is distinctly developed, the cleaved face exhibiting a pearly lustre. Cleavage parallel to Brachypinacoid is scarcely observable, but it can sometimes be recognised as distinct fissures in microscopic slides cut at right angles to the Vertical axis. The crystal has the tendency to separate along the Macropinacoid a, the plane of separation presenting an uneven surface. This is however not due to any interposition, as is usual in the massive variety of this mineral.

The phenomenon of pleochroism is very marked. The axial colours examined along the three pinacoidal faces gave with a section of nearly  $\cdot 5$  mm. ;  $\alpha$  = reddish-brown,  $\beta$  = greenish-yellow,  $\gamma$  = yellowish-green, with a weak absorption  $\alpha > \beta > \gamma$ . These characters agree with the observations of Hatch\* on the Rhombic Pyroxene of Charchani. In still thinner sections the pleochroism becomes very faint.

The section parallel to the Base, when examined under a convergent polarised ray, shows the emergence of the positive bisectrix  $\gamma$  the plane of the optic axes lying parallel to Brachypinacoid b, while in the section parallel to the Macropinacoid a, the negative bisectrix  $\alpha$  emerges perpendicularly.

The characteristics given above chiefly refer to the larger crystals which are found scattered within the glassy rocks, but the microscopic

\* Vulkangruppe von Arequipa—Tschermak's Min. u. Petro. Mitth. Bd. 7. 1887. p. 339.

examination has revealed the fact that innumerable crystals of the Rhombic Pyroxene are also developed in the glass in smaller but sharply defined forms which, though on the whole closely allied to those already described, exhibit certain differences in habitus. They are more slender in form, being elongated along the vertical axis. The pleochroism is very feeble; in still smaller crystals being hardly noticeable, transmitting only a very faint greenish colour.

Most of the crystals are formed of the faces  $a = \infty P \infty$  (100),  $b = \infty P \infty$  (010),  $m = \infty P$  (110), and  $i = {}_2P\bar{\tau}$  (211) as represented in fig. 2. The flatter pyramid  $e = P\bar{\tau}$  (212) appears rather seldom so that the crystal appears sharper at the terminations. Sometimes a pseudo-monoclinic form results by the shifting of the pyramidal faces  $i$  as in fig. 7. The plane-angle formed by the edges of the pyramid  $i$  over the vertical axis, when measured along the brachypinacoidal face  $b$ , is  $80\frac{1}{2}^\circ$ , while the corresponding angle when measured along the macropinacoidal face  $a$ , is always near  $120\frac{1}{2}^\circ$ \*

These crystals are found in all sizes usually .05—1 mm. in length, gradually passing to the larger forms.

*Twin.*—Numerous stellate aggregates of crystals are often observed under the microscope. This is probably due to the union of the crystals according to several twin-laws. One of these is a cross-shaped penetration-twin (fig. 6), in which the two individuals have the faces of the Brachypinacoid parallel to or coinciding with each other, and the directions of the vertical axes make an angle of  $60\frac{1}{2}^\circ$ . This twin is therefore analogous to that described by F. Becke,† the twinning-plane being Macrodome  $P \infty$  (101).

\* Rosenbusch gives the two values as  $80^\circ 52'$ , and  $120^\circ 38'$  respectively—Mikroskop. Physiogr. 2te Aufl. Bd. I, p. 392.

† Ueber Zwillingsverwachsungen gesteinsbildender Pyroxene u. Amphibole—Tschermak's Min. u. Petro. Mitth. Bd. 7. 1887. p. 95.



*Parallel-intergrowth of the Rhombic Pyroxene with a green Augite.*—

On examining the microscopic crystals of the Rhombic Pyroxene under crossed Nicols, it is found, as might have been expected, that they extinguish the light parallel and at right angles to the direction of the vertical axis. But the crystal is sometimes bordered on both sides by very narrow bands, in which the direction of extinction is oblique. This phenomenon is observed only when the crystal is found lying horizontally upon the macropinacoidal face  $a$ . The narrow bands show a simultaneous extinction of  $42^{\circ}$ – $45^{\circ}$  with the prismatic direction as represented in fig. 3. It may be observed that in the crystal here figured, the terminal faces are formed by the flat Pyramid  $c = P_{\infty}$ , a case rarely seen in the smaller crystals. The breadths of these bands are not constant; sometimes they become so narrow as to be almost inappreciable except by a most careful scrutiny.

This is a phenomenon arising from the regular intergrowth of the Rhombic Pyroxene with a Monoclinic Pyroxene. We must consider that the Brachypinacoid  $b = \infty P_{\infty}$  of the Rhombic Pyroxene is attached to the Orthopinacoid  $a = \infty P_{\infty}$  of the monoclinic Augite, the vertical axes of both crystals being parallel. Thus the macropinacoidal face  $a = \infty P_{\infty}$  of the former would become parallel to or coincide with the clinopinacoidal face  $b = \infty P_{\infty}$  of the latter, which would extinguish the light obliquely. In this position, the characteristic prismatic angles of the two Pyroxenes would come to similar position. Such parallel-intergrowth of the Rhombic and Monoclinic Pyroxenes was first observed by Trippke\* in a variety of Enstatite. It has also been recently observed in the Pyroxenes in some younger effusive rocks. Frederick H. Hatch† describes it as occurring in

\* Ueber den Enstatit aus den Olivenknollen des Gröditzberges—Neues Jahrb. f. Min. Geol. u. Pal. 1878. p. 673.

† l. c. p. 327.

Andesite from Arequipa in Peru ; and Judd,\* as occurring in the lavas of Krakatoa.

The narrow band of Augite just described may be also recognised by the fact that it is traversed by fine fissures running parallel to the direction of the vertical axis, and at right angles to it. Under polarised light Augite shows a decidedly stronger interference-colour than the Rhombic Pyroxene, so that the marginal bands are in vivid contrast with the median portion.

With regard to the microscopic characters of these crystals, the longitudinal section shows traces of prismatic cleavage-fissures running parallel to the longer sides. The basal section is quadrate, formed by the traces of the faces,  $\infty P \infty$ ,  $\infty P \infty$ , and  $\infty P$  at the corners, the cleavage-traces parallel to the last face being very distinct. The cleavage parallel to  $\infty P \infty$  is also occasionally observed as fine fissures. The basal section sometimes shows a peculiar zonal structure resulting from isomorphous layers. The central portion has, as shown in figure 12, a nucleus in its centre and is divided into two parts. It is distinctly pleochroic, being brownish  $\parallel$   $\alpha$  axis, and greenish-brown  $\parallel$   $\beta$  axis. The outer zone is of a faint brownish colour, and pleochroism is almost inappreciable. The central portion, which is evidently more ferriferous than the outer, must have crystallized before the less ferriferous portion. The crystals in general do not show any sign of alteration whatever.

*Enclosures.*—The most frequent enclosures are gas-pores, and glass-enclosures with fixed bubbles. The symmetrical arrangement of these enclosures is very characteristic. Figures 4, 5, 7, 9 illustrate the typical forms of this arrangement. The most frequent form is that shown in fig. 7, 9, the enclosures being arranged at both ends of the crystal conforming to the faces of the pyramid  $i = 2P\pi$ , i. e.,

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\* The lavas of Krakatoa,—*Geol. Mag.*, Dec. III, vol. V, 1888. p. 1.

four at each end. Sometimes they are more numerous at one end, being arranged one upon the other (fig. 5) or, rarely, in rows diverging from the centre (fig. 4). These phenomena indicate the inclusion of extraneous matter during the successive growths of crystals. A similar kind of symmetrical arrangement of enclosures has been described by E. Cohen\* in the Olivine entering into the composition of the lavas of Sandwich Island.

Sometimes we find very numerous glass enclosures of an elongated form running parallel to the direction of the vertical axis, such crystals presenting a hazy appearance in microscopic sections. They are shown magnified on the left hand side of fig. 4.

Very frequent mineral enclosures are certain small octahedra which are scattered within the crystal with no definite arrangement. They are often in very sharply defined forms, sometimes with their faces depressed in steps, and sometimes in twins, the twinning-plane being an octahedral face. The smaller crystals transmit a dark brownish colour, and are not affected by acids. They are most probably Picotite, an inference also supported by the presence of chromic oxide in the analysis given below.

The sample for the chemical analysis was obtained from specimens from Tatsumiura by separating with Thonlet's solution. The microscopic examination of the separated powder showed that there was much glass attached to the crystals. To remove this glass, the sample was lightly treated with hydrofluoric acid. A light green coloured residue was obtained, and the microscope showed that the glass was completely removed, and the smaller crystals came out in a very sharply defined form. The crystals were by this treatment scarcely attacked, but when the experiment was tried for a longer time, some of the crystals showed

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\* Ueber Laven von Hawaii und einigen andern Inseln des Grossen Oceans, nebst einigen Bemerkungen über glasige Gesteine im Allgemeinen.—Neues Jahrb. f. Min. Geol. u. Pal. 1880 II. p. 32

signs that they were beginning to be attacked. Peculiar transversal canal-like fissures were seen to traverse the crystal from both sides, on the pinacoidal faces, at right angles to the prismatic direction, as shown on the lower half of the crystal in fig. 5, probably corresponding to the line of chemical activity. The minute enclosures of Picotite could not be, in any way, removed. The sample thus obtained, was analyzed by Mr. T. Shimizu, to whom I here express my sincere thanks. The result of the analysis is as follows :—

Si O <sub>2</sub> .....	55·04 %
Al <sub>2</sub> O <sub>3</sub> .....	·88
Cr <sub>2</sub> O <sub>3</sub> .....	·49
Fe O .....	9·40
Mn O .....	·18
Ca O .....	1·55
Mg O .....	32·65
H <sub>2</sub> O .....	·45
	<hr/>
	100·64

Rejecting the small quantities of alumina, lime &c. in the above result, and calculating the rest up to 100, we have :—

			Ox. ratio.
Si O <sub>2</sub> .....	56·69 %	30·234 .....	14·05
Fe O .....	9·68 .....	2·151 .....	1
Mg O .....	33·63 .....	13·452 .....	6·25
	<hr/>		
	100·00		

From this we see that the composition may be represented by FeO. 6 MgO. 7 SiO<sub>2</sub>, which is equivalent to Fe Si O<sub>3</sub> + 6 Mg Si O<sub>3</sub>. This when calculated in percentage gives as follows :—

Si O <sub>2</sub> .....	57·38 %
Fe O .....	9·83
Mg O .....	32·79
	<hr/>
	100·00

Thus the Rhombic Pyroxene under consideration may be called *Bronzite*. The Rhombic Pyroxenes which have been recognised in Andesite and other effusive rocks, are so far usually of the more ferriferous kind known as Hypersthene. A well crystallized variety corresponding to the composition of Bronzite has hitherto been unknown to the writer. It ought to be remarked however, that the ratio of the two silicates  $\text{Fe Si O}_3$  and  $\text{Mg Si O}_3$  seems to vary to a certain extent in the different varieties of rocks in which they occur. Thus it is found that the specimens found in the dark porphyritic rocks are probably more ferriferous, as shown by their stronger pleochroism. It has also been indicated on page 79 that in the rock of Miyanoura, the crystal sometimes occurs built up of isomorphous layers, (fig. 12) also indicating this variation in chemical composition.

The mean specific gravity was found to be 3.305

With regard to hardness, it was found that the sharp edge of the Pyroxene can scratch the Adularia Felspar with ease; thus we may consider  $H = 6$ . The pyramidal face  $c$ , which is across the directions of the well-defined cleavage, is decidedly harder than faces lying in the prismatic zone; the latter can be scratched with difficulty with a sharp edge of the Felspar, but we have never succeeded in scratching the former. Thus on this face  $H = 6.5$ .

Thin pieces subjected to the tip of blow-pipe flame fuse at the edge, into a dark globule.

### A Green Augite.

The occurrence of a light greyish green coloured Augite in parallel-intergrowth with the Rhombic Pyroxene has already been considered. In some specimens of the glassy rock, we find the former more abundantly than the latter. At first sight, these two minerals when found together seem to be almost indistinguishable from each

other. On closer examination however, it is found that the Augite shows a stronger interference-colour. Also a certain section shows an oblique angle of extinction making  $40^\circ$  with the direction of the vertical axis, such being a clinopinacoidal section generally formed of the traces of the faces  $\infty P\bar{\infty}$ ,  $-P$ , o  $P$ .

The section at right angles to the vertical axis shows a trace of cleavage parallel to  $\infty P$ . Sometimes it is found that this section formed of  $\infty P\bar{\infty}$ ,  $\infty P\infty$ , and  $\infty P$ , is separated into two halves by a trace of a twin-boundary parallel to  $\infty P\bar{\infty}$ . As we cannot in general have the section falling exactly at right angles to the vertical axis, such a section generally shows a difference in the angular values of extinction, with respect to the line of boundary. This is in fact a common form of the Augite-twin, with  $\infty P\infty$  as a twinning face, which cannot of course be expected in the Rhombic system. In the ball-like masses of the glassy rock obtained from Ototojima this kind of Augite is specially well observed in association with the Rhombic Pyroxene, with Plagioclase both as well-defined crystals and as 'Rhombic lamellae,' and with some Picotite.

More usually, however, the Augite is developed in the glassy rocks of Chichijima as very slender crystals, sometimes almost filling up the entire glass-mass in confused aggregates so as to make the glass resinous in lustre. The development of these crystals, as indicated on pag. 70, is always rudimentary, having the tendency to assume fern-like shapes somewhat simulating the Pitch-stone of Arran in Scotland. The crystal always appears in elongated form along the vertical axis, the angle of extinction in clinopinacoidal section measuring nearly  $40^\circ$ . The cross section is always six sided formed by the prism-faces, and a pinacoid; the former presenting a peculiarly concave outline\* (fig. 13c). The

\* On account of the small size, and the curved character of the faces, the exact orientation of this section cannot be determined.

terminations of the crystal frequently end in fine filaments, which are often curved and branching into filiform threads (fig. 13a) shown magnified in fig. 14. Numerous longitudinal fissures as well as transversal clefts are also characteristically developed. The crystals are often found in irregular stellate aggregates, which are probably twin-groups. In some cases, the directions of the vertical axes differ by  $60^\circ$ . Sometimes a narrow median band is inserted, in which the extinction is straight (fig. 13b), showing that the Rhombic Pyroxene is in parallel-intergrowth with the Augite in the manner already described.

These rudimentary forms of the Augite-crystals are very characteristic in the glassy rocks of Bonin Island, especially of the rocks found near Ōmura and Kiyose in Chichijima. In the glasses of Miyanoura, and of Tatsumiura already mentioned as containing the crystals of the Rhombic Pyroxene, the monoclinic Pyroxene appears also in skeleton-forms, which, as may be seen from the accounts given below, must have had a close relation to the crystals of the Rhombic Pyroxene during their growth from the magma. A series of these micro-crystals are illustrated in fig. 15—20.\* The most simple form is a rod-like body bifurcated at both ends, or sometimes X shaped with numerous delicate spiny processes proceeding from the branches (fig. 20). These are very delicate bodies measuring nearly  $\cdot 025$  mm. in length. The fine processes usually become more elongated in larger forms, which measure  $\cdot 07$ — $\cdot 09$  mm. in length, and are so arranged that one set attached to one branch is always parallel to the other branches (fig. 15—18), these two sets being disposed nearly at right angle to

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\* These skeleton-crystals are strikingly analogous to those described by H. Vogelsang from a certain slag. (*Die Krystalliten*, p. 40. Taf. VI). The form assumed by these microlites also suggests an analogy with the so called "hour-glass shaped" structure found in some crystals of Augite. This structure is probably due to the unequal accretion of crystal-molecules in different directions as indicated by these rudimentary or so to say retarded crystals, combined with a certain chemical change during the growth of the crystal.

each other. These processes are not only peculiarly curved but somewhat rolled up along a certain axis, so that the entire shape often does not come out at once at one focal distance. However these bodies normally have their branches and processes extended along one plane. Their form usually assumes a rhomboidal outline as represented in fig. 15, 17, 18, or rarely disymmetric as in fig. 16. The form represented in fig. 18 reminds us of the clinopinacoidal section of Augite. Indeed it has been found that some of these well formed microlites extinguishes the light obliquely, the direction of extinction making  $40^\circ$  with the longer sides of the rhomboidal figure. It is to be noted that the smaller forms hardly exhibits an interference-colour.

A very interesting phenomenon which has been observed with regard to these skeleton-crystals is, that they are very frequently attached to the crystals of the Rhombic Pyroxene in a very regular manner. It is found that the crystals of the Rhombic Pyroxene, when looked at upon the macropinacoidal face  $a = \infty P \infty$ , have the angles and edges of the terminal pyramidal faces (i or e) set with several curved spines arranged in a very symmetrical manner. Fig. 3, 7—9, show such crystals. It will be found that at the solid angles of the pyramidal faces these spines are much larger than elsewhere and sometimes branching. They are always disposed in such a way that they all lie parallel to the macropinacoidal face  $a$ . Thus when these crystals are looked at upon the brachypinacoidal face  $b = \infty P \infty$ , these spiny processes appear all running in one direction as in fig. 6, 9, 11, i. e. parallel to the face  $a$ . There is no doubt as to the identity of these spines with skeleton-crystals of Augite already described, so that the regular attachment of the spines to the crystals of the Rhombic Pyroxene can be explained by the tendency which the Augite has to form parallel-intergrowth with the latter. The narrow bands of Augite attached to the crystals of the



Rhombic Pyroxene (described on pag. 78) sometimes run out into spiny processes at their terminations, and at the breaks formed by the transversal clefts (fig. 3). These Augite-bands however become very often exceedingly narrow, and then the spines appear as if they proceeded directly from the Rhombic Pyroxene crystals. From the appearances presented by the spines when looked at from the two pinacoidal faces, it is evident that they all run along a common plane, which would be parallel to the Macropinacoid  $a$  of the Rhombic Pyroxene. This fact shows that the micro-crystals of Augite are, as already indicated, flattened out along the clinopinacoid face, which, when they make parallel-intergrowth with the Rhombic Pyroxene, becomes parallel to or coincides with the Macropinacoid of the latter. Thus we see that this phenomenon represents a phase in the development of the two Pyroxenes, the molecules of which seem to have a marked tendency to unite themselves so as to come into similar positions. From their mode of growth it will be seen that the microlithic Augite has been attached to the Rhombic Pyroxene, after the latter has attained a perfect idiomorphic form, and hence the former must be in general younger than the latter. Various stages may, however, be observed under the microscope. Smaller crystals of the Rhombic Pyroxene have sometimes, on both ends, symmetrical pairs of simple processes as shown in fig. 19. Occasionally the rudimentary Augite-crystal is found having in its centre a band of the Rhombic Pyroxene as in fig. 15. These forms may again be traced to those in which a very narrow median band of the Rhombic Pyroxene is found between the slender form of Augite (fig. 13 b) which we have already considered.

Explanation of Plate XIV *bis*.

Fig. 1.—The crystal of the Rhombic Pyroxene frequently found at Tatsumiura as larger crystals, figured in the position of v. Rath (pag. 74–76).

Fig. 1 a.—The basal projection of the crystal shown in fig. 1.

Fig. 2.—The type of the microscopic crystals of the Rhombic Pyroxene, placed as in fig. 1. (pag. 77).

Fig. 3.—The crystal as in fig. 1, projected upon a plane parallel to Macropinacoid, the narrow bands of Augite on both sides making parallel-intergrowth with the crystal, as described on pag. 78, the direction of extinction in these bands being simultaneous and making  $42^\circ$  with the direction of the vertical axis, as shown by the oblique line. The spines proceeding from the Augite-bands explained on pag. 85.

Fig. 4.—The crystal, like that of fig. 2, projected as in fig. 3, to show the symmetrical arrangement of glass enclosures (pag. 79). On the left side are figured elongated enclosures which are sometimes arranged parallel to the direction of the vertical axis (pag. 80).

Fig. 5.—The crystal, as that of fig. 4, showing the succession of enclosures conforming to the pyramidal face i. In the lower part of the crystal are figured series of the canal-like figures produced when it is acted on for a long time by hydrofluoric acid (pag. 80).

Fig. 6.—The penetration-twin of the Rhombic Pyroxene projected as in fig. 3, 4, 5. The two individuals having their brachypinacoidal faces in common, and the directions of the vertical axes making ca.  $60^\circ$  (pag. 77). The spines of Augite attached at the angles are found to be running parallel with the face a (pag. 85).

Fig. 7.—The crystals, as in fig. 4, assuming a pseudo-monoclinic form, and showing the mode of attachment of Augite spines (pag. 85) and the symmetrical arrangement of enclosures at both ends of the crystal conforming to the Pyramid i. The black dots on the upper left-hand side, are the minute enclosures of Picotite.

Fig. 8.—The crystal, placed as in fig. 2, showing the symmetrical attachment of the branching skeleton-crystal of Augite (pag. 85).

Fig. 9.—The crystal, as in fig. 2, showing the appearance of symmetrical Augite-spines when looked at upon the face b. This is figured in the position adopted by Tschermak (pag. 75).

Fig. 10.—The same as in fig. 8, looked at upon the face a, with more thickly-set branching and curved spines.

Fig. 11.—The same as fig. 10, looked at upon the face b.

Fig. 12.—The cross section of the Rhombic Pyroxene showing characteristic cleavage-traces, and the difference in character between the inner and the outer portions (pag. 79, 82).

Fig. 13.—The crystals of Augite developed in glassy rocks. a.—A general habitus of the crystal with longitudinal and transversal striae, and the terminations ending in threads. b.—The same in parallel-intergrowth with the Rhombic Pyroxene. c.—The cross section of the crystal like a.

Fig. 14.—One of the forked terminations of the crystal as in fig. 13 a, magnified.

Fig. 15.—The micro-crystals of Augite among the glass (pag. 83), having in its middle a small band of the Rhombic Pyroxene.

Fig. 16.—The same as fig. 15, but disymmetric in form.

Fig. 17.—The same, peculiarly curved.

Fig. 18.—The same, showing the typical outline assumed by these crystals.

Fig. 19.—The smaller crystals of the Rhombic Pyroxene, having at

their ends simple spines of Augite (pag. 84).

Fig. 20.—The smaller forms of the Augite microliths.

Fig. 21.—The ‘Rhombic lamella’; the two individuals as a twin of the Carlsbad type (pag. 71). The upper individual shows an extinction-angles of  $40^\circ$  with the edge of P : M.

Fig. 22.—The same ; with the development of the face y, and the pyramidal faces in the zone of M : x.

Fig. 23.—The same ; the pyramidal faces being very distinctly seen in this crystal.





# PLATE I.

## Plate I.

Shimamura.

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*Fig. 1, 1a.*—*Dicksonia nephrocarpa* *Bunb. sp.*

*1b, 2, 2a.*—*Dicksonia acutiloba* *Hr.*

*3, 3a, 4.*—*Thyrsopteris prisca* *Eichw. sp.*

*5, 5a.*—*Dicksonia gracilis* *Hr.*

*6, 6a.*—*Thyrsopteris kagensis* *m.*

*7, 7a.*—*Adiantites Kochibeaus* *m.*

*8-10, 9a.*—*Pecopteris exilis* *Phill.*







# PLATE II.

## Plate II.

Shimamura.

*Fig. 1-3, 1a, 3a, 4a b c d.*—*Onychiopsis elongata* Geyl. *sp.*

*4e.*—*Ginkgodium Nathorsti* *m.*

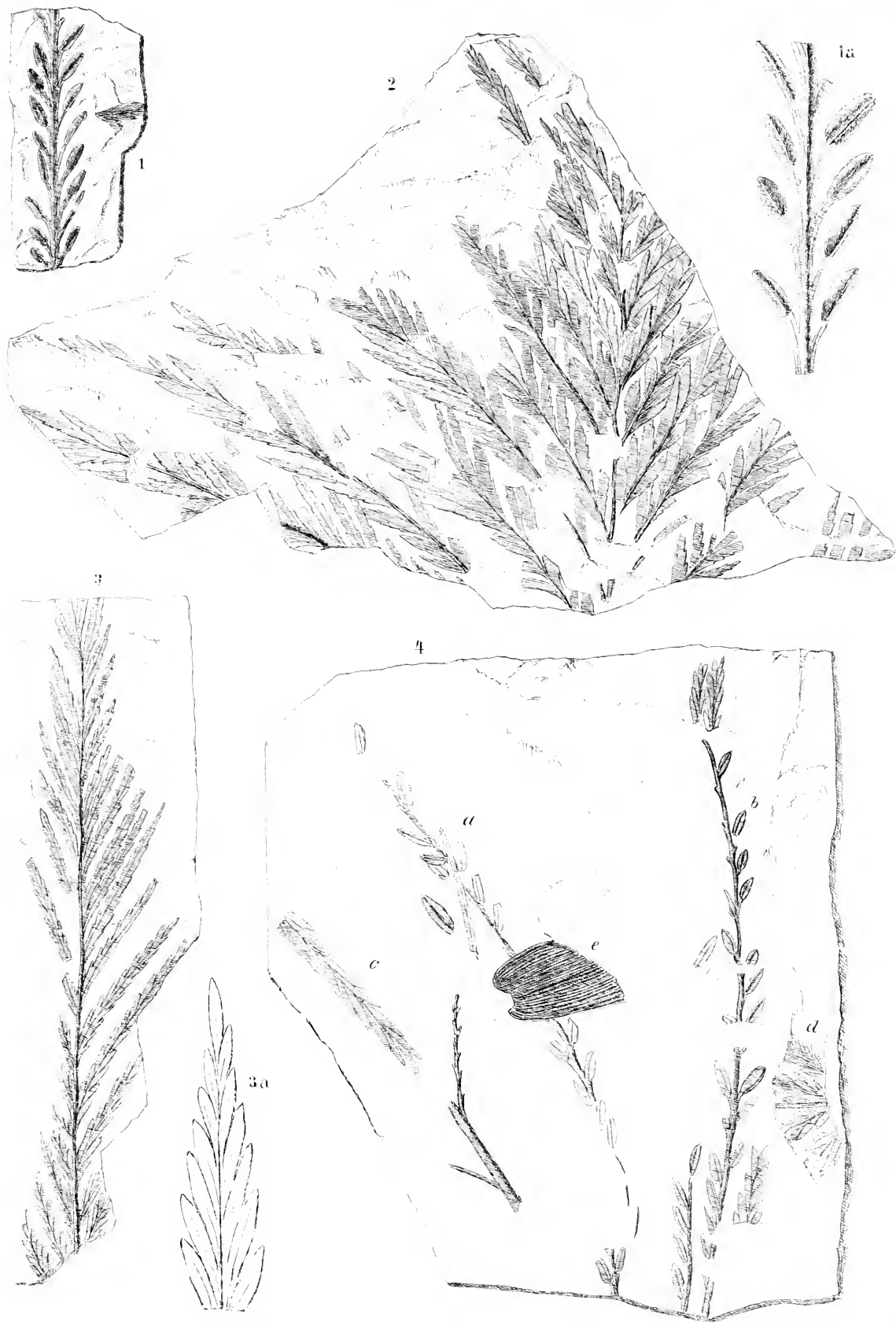




PLATE III.

**Plate III.**  
**Shimamura.**

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*Fig. 1.*—*Asplenium argutulum* *Hr. var.*

*2.*—*Asplenium distans* *Hr.*

*3.*—*Asplenium whitbiense* *Brgt. sp.*

*4, 5.*—*Macrotaniopteris Richthofeni* *Schenk.*

*Gabel, Ge.*—*Podozamites Reinii* *Geyl.*

*6d.*—*Onychiopsis elongata* *Geyl. sp.*

*7.*—*Ginkgodium Nathorsti* *m.*

*8.*—*Vallisneriites jurassicus* *Hr. (?)*.







PLATE IV.

## Plate IV.

Shimamura.

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*Fig. 1a.*—Podozamites lanceolatus *L. et H. var. Eichwaldi Hr.*

*Ib.*—Podozamites Reinii *Geyl.*

*Ic.*—Podozamites lanceolatus *L. et H. var. latifolia Hr.*

*2.*—Podozamites lanceolatus *L. et H. var. genuina Hr.*

*3a.*—Podozamites lanceolatus *L. et H. var. intermedia Hr.*

*3b.*—Podozamites Reinii *Geyl.*

*4a.*—Podozamites lanceolatus *L. et H. var. intermedia Hr.*

*4b, c.*—Podozamites lanceolatus *L. et H. var. Eichwaldi Hr.*





PLATE V.

## Plate V.

Shimamura.

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*Fig. 1.*—*Podozamites lanceolatus* *L. et H. var. latifolia* *Hr.*

*2a* (?) *2b.*—*Podozamites lanceolatus* *L. et H. var. Eichwaldi* *Hr.*

*3.*—*Podozamites lanceolatus* *L. et H. var. intermedia* *Hr.*

*4, 5a b c.*—*Podozamites lanceolatus* *L. et H. var. Eichwaldi* *Hr.*

*5d.*—*Podozamites lanceolatus* *L. et H. var.*

*6.*—*Podozamites lanceolatus* *L. et H. var. Eichwaldi* *Hr.*

*7.*—*Podozamites lanceolatus* *L. et H. var. intermedia* *Hr.*

*8.*—*Podozamites lanceolatus* *L. et H. var. minor* *Hr.*

*9.*—*Podozamites lanceolatus* *L. et H. var. intermedia* *Hr.*







PLATE VI.

## Plate VI.

Shimamura.

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*Fig. 1.*—*Podozamites lanceolatus* *L. et H. var. latifolia* *Hr.*

*2.*—*Podozamites Reinii* *Geyl.*

*3a.*—*Taxites* *sp.*

*3b d e, 4-7. 8a b c c.*—*Podozamites Reinii* *Geyl.*

*8d.*—*Nilssonia nipponensis* *m.*





PLATE VII.

## Plate VII.

Shimamura.

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*Fig. 1a b c, 1e.*—*Dioonites Kotai m.*

*1d.*—*Anomozamites sp.*

*2-7, 8a.*—*Nilssonia nipponensis m.*

*8b.*—*Podozamites lanceolatus L. et H. var. genuina Hr.*

*9.*—*Podozamites sp.*

*10.*—*Dictyozamites grossinervis m.*







PLATE VIII.

**Plate VIII.**

Shimamura.

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Ginkgodium Nathorsti *m.*

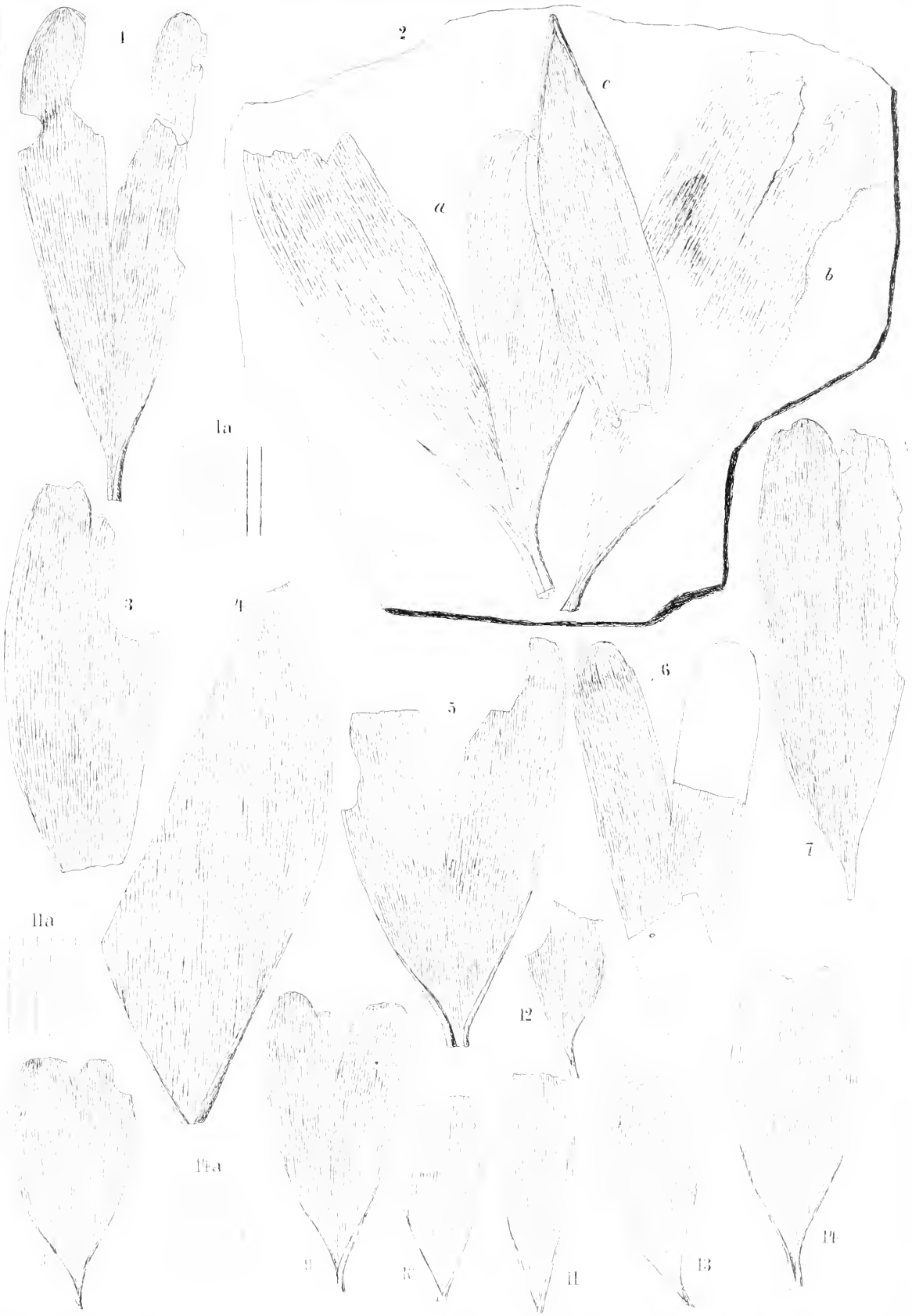




PLATE IX.

## Plate IX.

Shimamura.

*Fig. 1-10, 10a.*—*Ginkgodium Nathorsti m.*

*11.*—*Palissya sp.*

*12a.*—*Podozamites Reinii Geyl.*

*12b.*—*Pinus Nordenskjoldi Hr.*

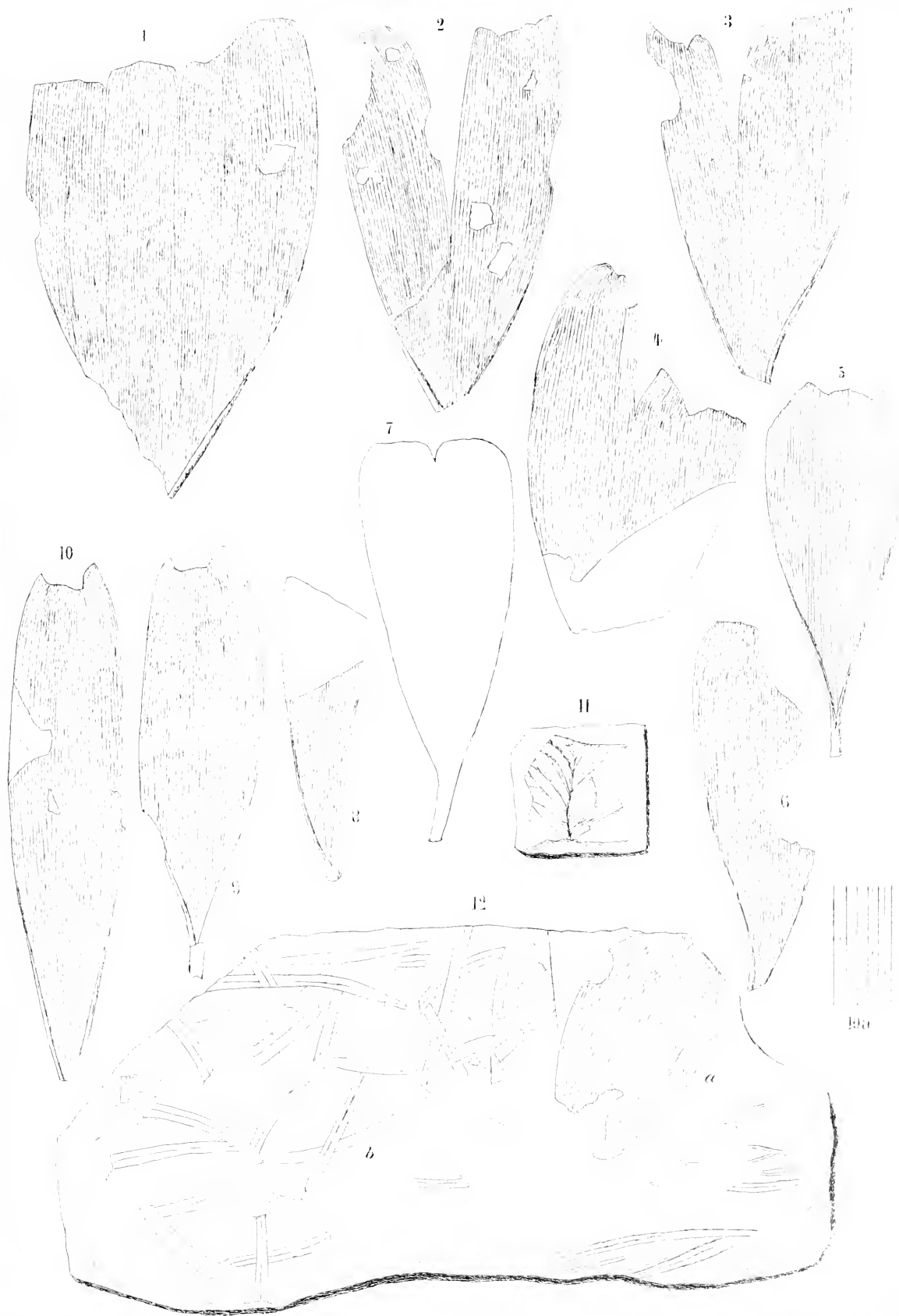






PLATE X.

## Plate X.

Ozō.

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*Fig. 1. 2a.*—*Asplenium whitbiciense* *Brgt. sp.*

*2b.*—*Nilssonia ozoana m.*

*2c.*—*Taniopteris* (?)

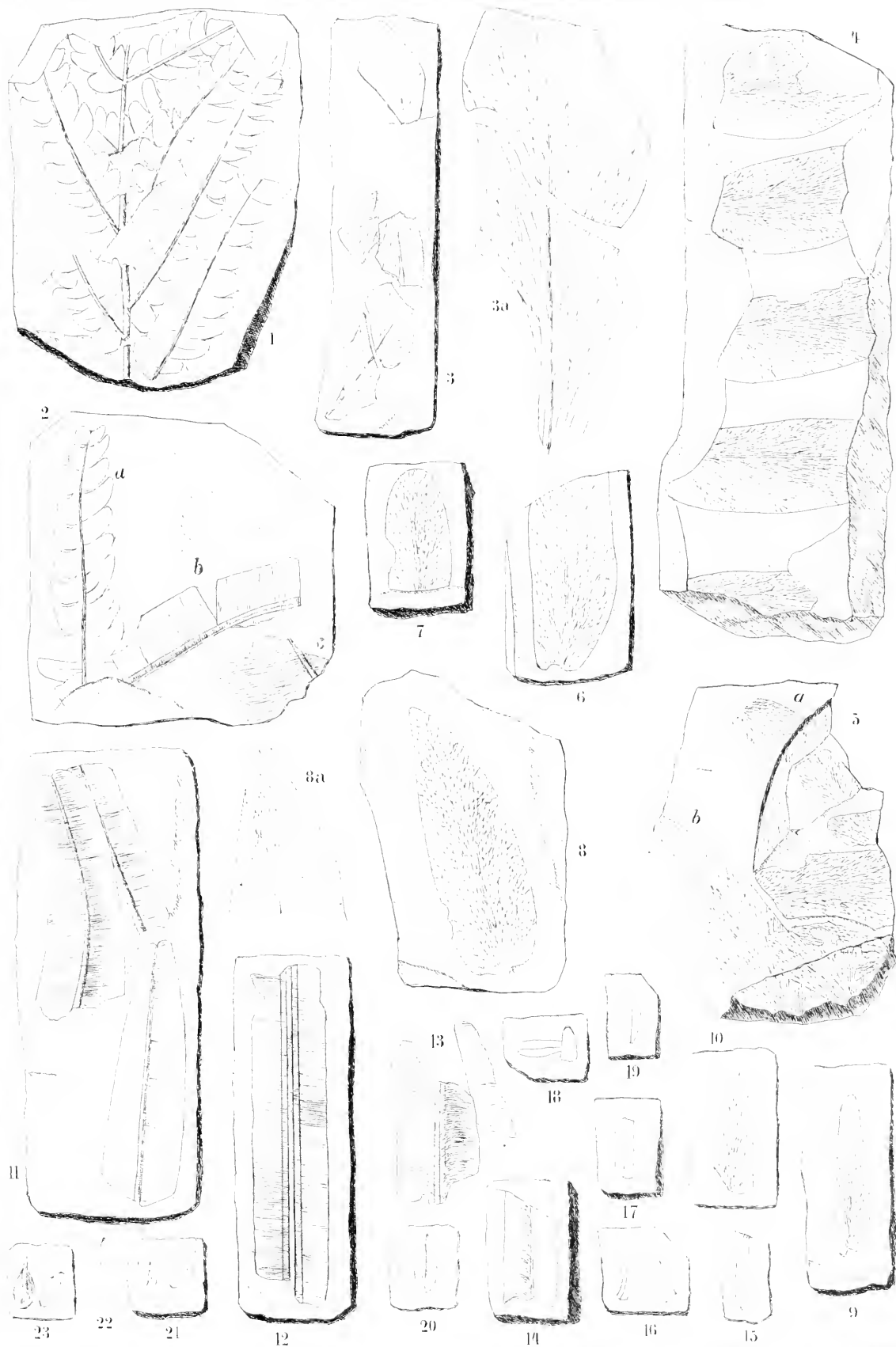
*3, 3a.*—*Sagenopteris sp.*

*4-10, 8a.*—*Dietyozamites indicus Estm. var. distans m.*

*11-14.*—*Nilssonia ozoana m.*

*15-19.*—*Taxites sp.*

*20-23.*—*Carpolithes ginkgoides m.*





# PLATE XI.

## Plate XI.

### Ushimaru.

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*Fig. 1-3.*—*Equisetum ushimarense m.*

*4.*—*Asplenium distans Hr.*

*5.*—*Dictyozamites indicus P'stm. var. distans m.*

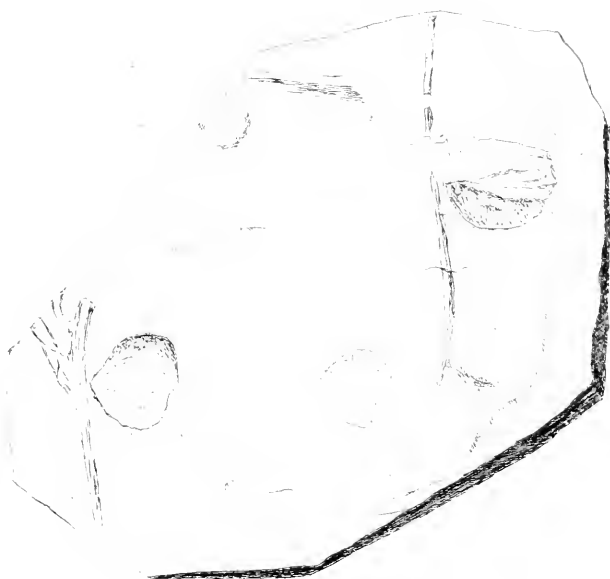
*6.*—*Podozamites lanceolatus L. et H. var. (?)*.

*7.*—*Thyrsopteris kagensis m.*

1



2



4



7



5



6







PLATE XII.

## Plate XII.

Shimamura.

*Fig. 1, 1a b, 2.*—*Adiantites Heerianus m.*

*3.*—*Pinus* cf. *prodromus Hr.*

Okamigō.

*4.*—*Podozamites Reinii Geyl.*

*5.*—*Thyrsopteris Murrayana Brgl. sp.*

*6.*—*Nilssonia nipponensis m.*

*7.*—*Equisetum sp.*

*8.*—*Asplenium argutulum Hr.*

*9, 10.*—*Onychiopsis elongata Geyl. sp.*

*11.*—*Czekanowskia rigida Hr. (?)*

*12, 12a.*—*Podozamites sp.*

*13.*—*Dicksonia gracilis Hr.*

*14, 15.*—*Ginkgodium Nathorsti m.*

*16, 17.*—*Taxites sp.*

*18.*—*Podozamites lanceolatus L. et H. var. brevis Schenk.*

*19.*—*Podozamites tenuistriatus Geyl.*





# PLATE XIII.

## Plate XIII.

Okamigō.

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*Fig. 1.*—*Nilssonia nipponensis m.*

2.—*Ginkgo digitata Brgt.*

Ozō.

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3.—*Nilssonia (?)*.

4.—*Asplenium distans Hr.*

5-8.—*Vallisneriites jurassicus Hr. (?)*.

9.—*Asplenium argutulum Hr.*

10.—*Czekanowskia rigida Hr. (?)*.







PLATE XIV.

## Plate XIV.

Hakogase.

*Fig. 1.*—*Asplenium distans* Hr.

*2.*—*Asplenium argutulum* Hr.

*3, 3a.*—*Adiantites lanceus* m.

*4-9.*—*Nilssonia orientalis* Hr.

*10.*—*Ginkgo* cfr. *lepidus* Hr.

*11, 11a, 12a.*—*Dicksonia* cfr. *Glehniana* Hr.

*12b.*—*Podozamites lanceolatus* L. et H.

*13, 13a.*—*Sphenopteris* sp.

*14.*—*Dicranites Kotoei* m.









# **The Eruption of Bandai-san.**

By

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and

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Assistant Professor of Geology, Imperial University.

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With Plates XV–XXIV.

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When the news of the eruption of Bandai-san in the Province of Iwashiro, which took place on the morning of July 15th, 1888, was received in Tōkyō, the President of the Imperial University directed us to proceed at once to the spot and to fully investigate that terrible subterranean convulsion and its attendant phenomena. We started from the capital on the 18th and arrived at the scene of the disaster on the 19th. During the next ten days we made several ascents and descents by different routes, travelled over the devastated lands, and collected all the information that we could by examination and inquiry on the spot. In order, however, to perfect our investigations, we determined to camp for some days on the volcano, and at the same time to survey the dimensions of the newly opened crater and therefrom to estimate the cubic content of the mass that had been blown away. At our request, the President despatched Mr. I. Toya, C.E., a graduate of the University, to take charge of the surveying work. Equipped with provisions, theodolite, levels, and other instru-



ments, we ascended on July 31st and remained on the summit till the 8th of October. It was mainly owing to Mr. Toya's patient labour that we were enabled to arrive at the valuable conclusions deducible from the survey. The spot selected for our camp was Nakanoyu, a spa almost on the very edge of the crater, that is to say, not more than one hundred metres from it—a position admirably suited for our purposes. Though so close to the volcanic focus, the spa had escaped total destruction, being situated at the back of the crater, and screened by a hillbrow from the direct effects of the explosion. As might be expected, our surveying and other works on the summit, the fruits of which are embodied in this paper, were not unattended by discomforts and difficulties—such, for example, as indifferent food, breakneck ascents and descents, foul vapours, chilly nights, and long sultry summer days spent in scrambling over a scorched and barren crater.

Soon after the eruption we sent letters of inquiry to a large number of schoolmasters and local officers in the neighbouring provinces; accounts given by other observers, as well as those published in newspapers, were also duly considered. The information embodied in the answers to our letters was very valuable for the purposes of this paper, especially in preparing Plate XXIV, and we take this opportunity of expressing our sincerest acknowledgment to all who thus helped us. We also tender our best thanks to the colleagues and friends who have since assisted us, by suggestions and otherwise, especially to Major-General Palmer, R. E., for kindly helping us with our English and for many valuable hints.

The questions we asked in our letters were mainly as follows: The names and addresses of the observers. The times at which they first noticed the eruption. Did they hear the sound of the explosion? Its nature, duration, loudness, etc. Did they see steam (com-

monly called smoke) rising up in the air? Its colour, height, form, etc. Did they see lightning in the steam, or fire on the volcano? How did the lightning or fire look? Did volcanic dust fall? Its thickness, colour, consistency, structure, etc. Were there any earthquakes either before or after the eruption? Their times of occurrence, intensity, duration, nature, etc. The state of lakes, rivers, and springs before and after the explosion. The meteorological conditions, especially the force and direction of the wind. Any other information bearing on, or which might seem to bear on, the eruption was also asked for. The answers to these questions are given in a tabular form at the end of this paper.

### **Bandai-san, considered topographically and geologically.**

In Northern Japan, there run along the Pacific seaboard two principal masses of mountains, chiefly composed of crystalline and older rocks. The more northerly of the two, on the eastern side of the Kitakami River, has been named by Dr. E. Naumann the Kitakami Mountain-land, and the other, situated to the east of the Abukuma River, the Abukuma Mountain-land. These two mountain-masses are remarkably similar in their geological structure, and the principal direction of strike is north and south. They are very old formations, consisting of granite, granite-gneiss, gneiss, and other crystalline schists, together with thick accumulations of Palaeozoic strata, much folded and faulted, and some patches of Mesozoic strata not less disturbed. We have, in fact, the relics of old land, the principal features of which must have been determined at the end of the Mesozoic Era, and much of which has, no doubt, been subsequently denuded away.

On their western sides, the two mountain-lands face broad valleys, in which the rivers already mentioned run in a meridional

direction—the Kitakami from north to south, and the Abukuma from south to north—and along which passes the chief highway of Japan. The valleys separate the Abukuma and Kitakami ranges from a high ridge which, traversing the middle of Northern Japan, forms structurally the backbone of the region, and constitutes the main watershed between the Pacific Ocean and the Japan Sea. This central ridge owes its origin to volcanic effusions of comparatively younger date, and consequently the natural barrier thus created is made up mostly of prominent volcanic peaks, and differs in its features from the neighbouring old land. The more important of the volcanic peaks are, Osore-yama and Yake-yama on the extreme north of the main island, and thereafter Ganju-san, Komaga-take (Province of Rikuchū), Zoō-zan, Azuma-san, Bandai-san, Nasu-dake, Shirane-san (Province of Shimotsuke), Akagi-san, &c. These mark the course of the line of weakness along which terrestrial disturbances of varying degree have manifested themselves, in times past, attaining their climax during the Tertiary Era, and thereafter declining into their present state of comparative quiescence.

Bandai-san (Lat.  $37^{\circ} 36' N.$ , Long.  $140^{\circ} 6' E.$ ) is situated in the Yama District (*kōri*) in the Province of Iwashiro, immediately adjacent to the Abukuma mountain region, a part of which, formed of granite and gneiss, borders the east bank of the river Nagase that runs immediately past the foot of the volcano. Besides Bandai-san, there are in this part of the country several other volcanoes, both active and extinct, as shown in Pl. XXIV; the line of principal volcanoes belonging to the central ridge of Northern Japan, already referred to, is shown in the same Plate by a broken line. On the north-east of Bandai-san are Dake-yama and the Azuma-san group, the latter consisting of three principal peaks called the Eastern, Western and Middle Azuma; while on the south are Nasu-dake, Takahara-yama, &c.

Immediately north-west of Bandai-san there is a small lake called Okuni-numa, at an elevation of 1065 m. above the sea-level, and surrounded on all sides by ridges, the highest of which is called Nekoma-yama, and rises 305 m. above the lake. Judging from its features, Okuni-numa is unquestionably an old crater. Between it and Bandai-san there stands a round-topped hill, till lately overgrown with forest, and known as Marumori-yama, which is apparently a small volcanic cone. The few naked tree-trunks, stripped of branches and leaves, that are now to be seen on this hill-top vividly attest the severity of the recent eruption.

From the fact that the older rocks of the Abukuma mountain-land underlie the volcanic groups in the vicinity of Bandai, it seems reasonable to infer that the volcanoes originated on the fractured edges of the old formation.

Though all of the volcanoes that have been in eruption in recent times are shown as active on Plate XXIV, it is to be understood that such activity never exceeded intensified solfataric explosions, disturbing the upper crust alone. The late explosions of Nasu-dake and Azuma-san were of this class only, neither lava nor pumice having been ejected. The extreme volcanic energy which once raged in the district of Bandai seems to have gradually waned down to the present time. Denuding action has evidently played a more prominent part than plutonic agency in changing the forms of the mountains, and the decomposition of the rocks has produced a thick layer of soil, supporting a dense forest-growth, and concealing the old lava-flows and scoriaceous ejections which attest the volcanic origin of the hill-masses. Peasants worked daily among the green forests of Bandai, to collect fuel and to fell trees, wholly unsuspecting of the calamity that hung over them.

The district about Bandai-san is made up principally of tufa-

ceous deposits and sheets of volcanic rock, forming the basis of an elevated area known as the Aizu Plateau, which includes the districts of Yama, Aizu, Kawanuma and Ōnuma, in Iwashi-ro, its average height exceeding 500 m. above the sea-level. This plateau is surrounded on all sides by mountains of volcanic origin. On its southwest border stand the extinct volcanic peaks of Hakase-yama, Mikagura-dake &c., and on the south the conspicuously flat-topped Nunobiki-yama, formed of volcanic sheets. Among these mountains are found numerous hot springs, more than 30 of which have been counted.

The streams which rise in the surrounding mountains discharge into a depression on the south side of Bandai, there forming the Lake Inawashiro, which is one of the largest in Japan. This lake, the surface of which is 496 m. above the sea-level, is not a true crater-lake as is sometimes supposed. Its principal feeder was the river Nagase, flowing from the northern part of Bandai. The upper course of this river was, however, entirely stopped by the falling *débris* during the recent eruption, and the lake is now supplied mainly by its tributary, Sukawa, flowing from Azuma-san. The lake discharges northwestward, at the village of Tonokuchi, by a stream which flows through the Aizu Plateau under the name of Nippashi-gawa for about 19 kilometres, then joining the Aka-gawa. The latter stream collects all the waters of the Aizu Plateau, and finally runs into the Japan Sea near the port of Niigata. Recently another outlet was made on the eastern side of the lake, by means of a canal for irrigation.

It seems probable that the Inawashiro Lake fills up a depression formed by evisceration of the ground, resulting from the copious outpourings of volcanic products in its vicinity, notably those of Bandai. The origin of the lake, according to current tradition, is ascribed to a great terrestrial disturbance which took place in the

ninth century. The districts known as Tsukinowa and Sarashina, consisting of 49 villages, are said to have been submerged on that occasion.

The name Bandai-san is usually given to a group of peaks, consisting of Ōbandai, Kobandai (lately destroyed), Kushiga-mine, and Akahani-yama, surrounding an elevated plain called Numano-taira. (Pl. XV). This group, standing on the northern side of Lake Inawashiro, forms a very conspicuous object in the landscape, and displays the characteristic outlines of a volcanic mountain. When seen from the southwest side, from the town of Wakamatsu, it appears as a single pointed peak. It has sometimes been called the "Fuji of Aizu," from its resemblance to the well known Fuji-yama. Ōbandai, or Great Bandai, is the most prominent of the peaks, its summit being 1840 m. above the sea-level. It presents a highly rugged and precipitous escarp toward the Numano-taira, exposing volcanic strata which are the results of accumulations of augite-andesitic lava and scoriae during its period of activity. Viewed at a distance from the east, Ōbandai has a highly characteristic appearance, descending by a very steep slope toward the central plain and by a gentle one in the opposite direction. Kobandai, or Little Bandai, was less known, on account of its being situated far away from the inhabited portions of the Aizu Plateau, and being also partly screened by its more prominent sister peak. From the latter fact it appeared to be lower than Ōbandai, and was therefore so regarded; and hence its name. But careful examination has shown that they were probably of almost identical height, as will appear farther on.

It is probable that the plain Numano-taira is the remains of the original crater—Atrio—and that the several peaks above mentioned are parts of the Somma-wall which encircled it. But gradual denudation during long periods of quiescence, together with occa-

sional rendings of the crater-wall when explosions took place, have brought about the present form, namely, that of separate masses presenting more or less conical shapes. In the Numano-taira, or "plains with ponds," there were several small lakes or pools, as is usual in craters of this nature. Nearly in its centre, there existed before the eruption a solfatara on a small hillock called Iwō-yama, or "sulphur mount," from which sulphur was collected by the neighbouring villagers. The plain was also covered with dense forests, which were destroyed on the 15th of July.

The flanks of Bandai are cut into numerous channels called "sawa." The largest of them is that known as Biwa-sawa, which opens eastward from the Numano-taira. It was down this ravine that the smaller stream of mud and rock descended in the late eruption. Seen from the east, it presents a very conspicuous appearance. Fig. 2, Pl. XVII, is a sketch made of this part of the mountain immediately after the eruption. From our point of view we had a magnificent prospect of Ōbandai, with its rugged and precipitous wall on the northern side. The plain of Numano-taira is seen to terminate in a very steep cliff, known as Futatsu-iwa, at which place the water of the lakes in the above plain made a sudden leap, forming a high waterfall. Immediately below this is a small depression called Hikage, which has been regarded by some as a secondary crater of the late eruption. Another large ravine is that lying between Ōbandai and Akahani-yama, opening southward, and named Katsura-sawa. There is also a bare glen on the southern flank of Ōbandai, known as Kara-sawa. These ravines or valleys may be considered to have been chiefly modelled by the paroxysmal explosions which, as the history of the mountain tells us, took place at intervals in past times. Denudation, however, has doubtless modified their original forms. The same remarks may be held to apply to the topographical features of the

whole mass. For, not only must the original form of the mountain have suffered by the successive eruptions, but the *débris* thus produced, obstructing the water-courses, must have gradually brought the surface to its present form. Some of the outbursts would seem from the history of Bandai-san to have been very similar in character to that of the 15th of July last.

The hot springs on the north-western side of Bandai, known as Bandai-no-yu, were latterly the principal remnants of the volcanic forces which once raged with so much vigour. There were three of these springs, all celebrated for their curing effects upon various diseases. They were known as Kami-no-yu, Naka-no-yu, and Shimo-no-yu, respectively meaning the upper, middle, and lower bath, where small huts had been constructed for the accommodation of bathers, who flocked thither in summer from various parts of the neighbouring district. They were sulphur springs originating in solfatara formed by the issuing of steam and sulphuretted hydrogen from numerous rock-fissures.

Several years before the eruption Prof. J. Milne,\* of the Imperial University, ascended Bandai-san, when he took a sketch and described it, classifying it as an active volcano.

### Traditions and History.

According to tradition, Bandai-san was originally a single massive peak, the summit of which was burst open in olden times by a volcanic eruption, and split into several peaks, the event being productive of a terrible catastrophe. The *débris* of the explosion descended on all sides of the mountain, and the two districts Tsukinowa and Sarashina, containing some fifty villages, were engulfed beneath

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\* The Volcanoes of Japan—Transactions of the Seismological Society of Japan, Vol. IX. Part II.



the area thereafter occupied by Lake Inawashiro. This account of the splitting of one large mountain into several minor peaks is interesting, as it agrees with the suppositions suggested by the structure of the volcano. For, as has been previously explained, the several ridges together constituting the Bandai group surround an elevated plateau which has all the appearance of an old crater.

Another tradition, apparently referring to the same event, says that in the first year of Daidō (806 A. D.) Lake Inawashiro was suddenly formed, and in it a small island, now called Okina-shima, appeared.

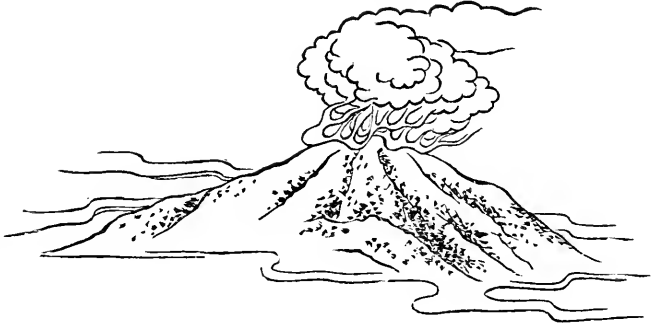
Religious traditions, on the other hand, not unnaturally connect the catastrophe with demoniacal agencies. A Buddhist temple in a village near Bandai-san contains a document, said to chronicle its founding, which runs thus: "In olden times there used to dwell about Bandai devils who did much harm to the inhabitants; in the year of Daidō numbers of people living at the foot of the mountain were swallowed beneath the earth, and there was left a great lake (Inawashiro). The reigning Emperor, in order to subjugate the evil spirits which were probably the cause of all these terrestrial mysteries, despatched the famous priest Kūkai, who, on arrival at the spot, performed ten days' secret prayer to Buddha, when the devils were compelled to vacate Bandai and to flee to the neighbouring mountains. In commemoration whereof, Kūkai caused this temple of Dainichi-ji to be built."

Several ancient records describe the mountain as having at various times smoked and ejected fire and poisonous vapours. Such accounts are highly interesting, especially when we consider the volcano's apparent quiescence for ten centuries. We give below translations of some of the records published by the Geographical Bureau, with remarks on them.

The *Koden* (古傳, Old Tradition) says: “This mountain vomited fire; and sulphur was spread over the country for 10 *ri* around, its vapour being injurious to health. After Lake Inawashiro was formed, the fire ceased and the vapour was dispersed.”

The *Tōgoku Ryokōdan* (東國旅行談, Travelling Tales in Eastern Provinces) says :

“To the east of Lake Inawashiro there stands a steep peak called Bandai-san ; from its high summit ascend blazing fire and smoke,



as if to burn the firmament.” This account is followed by an illustrative sketch, as in the accompanying wood-cut, of the volcano belching forth fire and smoke.

In the *Ōu Benranshi* (奥羽便覽誌, Handbook on Ōu Provinces) the following account is given: “Aizu-yama, commonly called Bandai-san, lies to the east of Lake Inawashiro ; from its top ascends burning smoke.”

It sounds strange to hear of flame and fire ; but we ought not to put much confidence in the tales of travellers, which are too often exaggerated and grossly inaccurate. Though the phenomena caused by streams of molten lava in volcanic eruptions are commonly spoken of as presenting the appearance of flames and fire, we do not find in Bandai-san any indication of lava-flows that can have taken place within historical times. It may be added, however, that there are cases on record in which flames caused by the combustion of gases have been a feature of volcanic outbursts.

The *Shinpen Aizu Fūdoki* (新編會津風土記, Accounts of Aizu)

says: "In olden times the destruction of a part of Bandai-san gave rise to Akahani-yama. The effects were very violent and extensive; earth and stones falling down dammed the stream of Sugawa and inundated Ihibara." To the north-west of Oda village there are places respectively called Ōnamiyose (large wave beach) and Konamiyose (small wave beach). These localities, it appears, were formerly washed by the waters of lakes formed on the occasion above referred to, which, however, subsequently disappeared. As to the cause of this destruction of Bandai-san, it is not clear from the description whether it was volcanic or otherwise, but the phenomena exhibited seem to have been similar in character to those of the late eruption. Besides, there are authentic records of other terrestrial disturbances of much younger date, though perhaps of less magnitude, which have occasionally troubled this part of the country. These accounts seem to attest successive outbreaks of the same store of energy that wrought such havoc on the 15th of last July.

In the 8th month of the 16th year of Keichō (1611), a violent earthquake occurred at Bandai, and the fall of earth and rocks that was produced by this convulsion dammed up the river Nippashi, the outlet of Lake Inawashiro, and resulted in the formation of three new lakes. Water issued in great quantities from fissures opened in the ground. Accumulations of water, caused by the stoppage of streams, formed several other lakes, and in one place a waterfall of considerable height. In the villages of Matsuno and Terauchi some temples were overthrown; and there were innumerable damages of other kinds. In spite of the efforts of Gamō, the ruling Daimyō, who employed large numbers of men to cut an outlet for the accumulated waters, inundation spread over the districts Yama and Kawanuma, producing a lake at Yamazaki; and it was not until after several engineering attempts that a passage was effected, by the aid of which

about one-half of the inundated area was at length reclaimed.

During the period Hōreki (1751-1783), another convulsion took place in Mount Hanzawa, and created the present lake of that name.

The last recorded disturbance, although its particulars are not known, is said to have taken place about 80 years ago, when several lakes in Numano-taira were filled up, and great quantities of *débris* descended by the Biwa-sawa. Traditions and tales relating to this event were cherished with superstitious fear by the peasantry of the region, and listened to with wondering awe by the children, until there fell upon them the yet more terrible catastrophe of last July, which we now proceed to describe.

### Eruption and Attendant Phenomena.

On the morning of July 15th, 1888, the weather in the Bandai district was fine, there being scarcely a cloud; and a gentle breeze was blowing from the W.N.W. Soon after 7 o'clock, curious rumbling noises were heard, which the people thought to be the sound of distant thunder, often heard among the mountain-tops. At about half-past 7, there occurred a tolerably severe earthquake, which lasted more than 20 seconds. This was followed soon after by a most violent shaking of the ground. At 7.45, while the ground was still heaving, the eruption of Kobandai-san took place. A dense column of steam and dust shot into the air, making a tremendous noise. Explosions followed one after another, in all to the number of 15 or 20, the steam on each occasion except the last being described as having attained a height above the peaks about equivalent to that of Ōbandai as seen from Inawashiro, that is to say, some 1,280 m, or 4,200 feet.

The last explosion, however, is said to have projected its discharge almost horizontally, towards the valley on the north. And, considering the topography of the mountain and the form of the crater,

it is probable that previous discharges were also more or less inclined to the vertical, in a northerly direction. The main eruptions lasted for a minute or more, and were accompanied by thundering sounds which, though rapidly lessening in intensity, continued for nearly two hours. Meanwhile the dust and steam rapidly ascended, and spread into a great cloud like an open umbrella in shape, at a height equal to at least three or four times that of Ōbandai. This cloud was gradually wafted away by the wind in a southeasterly direction. At the immediate foot of the mountain there was a rain of hot scalding ashes, accompanied by pitchy darkness. A little later, darkness was still great, a smart shower of rain fell, lasting for about five minutes. The rain was quite warm. These phenomena, as well as the terror and bewilderment which they caused among the peasantry, were described in thrilling terms by the newspapers of the day. While darkness as aforesaid still shrouded the region, a mighty avalanche of earth and rock rushed at terrific speed down the mountain slopes, buried the Nagase valley with its villages and people, and devastated an area of more than 70 square kilometres, or 27 square miles.

Mr. Tsurumaki, a priest of Echigo, who was staying at the Nakanoyu spa on the edge of the crater at the time of the eruption, and who escaped death almost miraculously, sent us soon afterwards the following interesting and minute account of his terrifying experiences: "I started from my native village on the 8th of July, in company with four of my friends, for Bandai-san, and arrived there on the 12th, *i. e.* three days before the catastrophe. I had been there before, in July, 1885, when I stayed three weeks. On the day of my recent arrival (the 8th) the fog was unusually dense, and the volume of steam at Kaminoyu seemed to have lessened. On the 13th the fog was denser still, and remained so till the evening. The 14th was a bright day, the fogs of the previous days having cleared up. From

Account of an  
eye-witness.

about 10 o'clock in the morning of this date the flow of the spring began to diminish. But the fact that the amount of discharge is smaller in fine weather and larger in cloudy days is well-known among bathers, so that we gave no heed to it. The morning of the 15th, which was the fatal day, dawned with a bright and pleasant sky, and the flow of the spring was as usual. At about 8 o'clock, however, there was a fierce convulsion of the ground, and we all rushed out of the house. In about 10 minutes (seconds?), while we were fearfully wondering what was the matter, a terrible explosion suddenly burst out from the slope of Kobandai, about one *chō*\* above a place at which steam has been issuing from time unknown. This was followed by a dense mass of black smoke, which ascended into the air and immediately covered the sky. At this time, showers of large and small stones were falling all about us. To these horrors were added thundering sounds, and the tearing of mountains and forests presented a most unearthly sight, which I shall never forget while I live. We fled in all directions, but before we had gone many metres we were all thrown prostrate on the ground. It was pitchy dark; the earth was still heaving beneath us; our mouths, noses, eyes and ears were all stuffed with mud and ashes. We could neither cry out nor move. I hardly knew whether I was dead or in a dream. Presently a stone fell on my hand, and I knew I was wounded. Imagining, however, that death was at hand, I prayed to Buddha. Later, I received wounds on my loin, right foot, and back. After the lapse of an hour the stones ceased to rain and the atmosphere had cleared from darkness to a light like moonlight. Thinking this a fine opportunity to escape, I got up and cried, 'Friends, follow me!'; but nobody was there. When I had descended about two *chō*, there was a second, and after another *chō*, a third explosion. In these sand

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\* One *chō* is nearly equal to 100 metres.

and ashes were ejected, but no stones. I reached Ōdera at noon, and there I received surgical treatment, etc.”

Deluge of rock  
and earth.

The most striking feature in the whole of this eruption was the deluge of rock and earth. Notwithstanding the violence of the phenomena, and the completeness with which the mountain was destroyed, the nature of the eruption was comparatively simple. The destructive agency was merely the sudden expansion of imprisoned steam, unaccompanied by lava flows or pumice ejection. When the explosion took place, a considerable amount of rocks and earth was projected into the air, and a part diffused in the form of dust, but by far the greater part of the bulk of Kobandai was just split into mighty fragments, which were thrown down much after the manner of a land-slip. Descending the mountain sides with ever accelerating velocity, the components of these avalanches were dashed against obstacles in their way and against each other, and were thus rapidly reduced to confused masses of earth and rocks. The loose and friable *débris* thus produced ultimately lost its adhesive power, and may have been compared with a little exaggeration to sand. If we suppose a mass of some 1.21 cubic kilomètres, or 1,587 millions of cubic yards (which was the actual volume of the mountain destroyed), of sand to be suddenly precipitated from a lofty summit, it would flow down the sides in a torrent not very unlike that of water. That the earth and rock *débris* did flow down in this way we were convinced by examining the actual state of things on the spot, and more particularly by witnessing afterwards with our own eyes a very similar phenomenon, though on a vastly smaller scale.

One day, while we were at work in the crater, a huge slice of the precipitous wall of rock that had been bared by the explosion fell suddenly and crashed with a tremendous uproar down the steep incline beneath. This slab fell from a place about 300 mètres high. The

great masses of earth and rocks were shattered as they fell, and broken up into pieces, ever growing smaller as they descended. The behaviour of this pulverized mass resembled the rush of a headlong torrent. Although boulders measuring 10 mètres or more in diameter were mixed up with finer matter, as a whole the movement approximated to that of a fluid. No words can describe the fierceness and force of that impetuous downpour—its mad surgings this way and that, and the bold leaps with which it would now and then bound over low ridges that hindered its progress, and shoot onward down the neighbouring depression. It was a magnificent but somewhat awful sight to witness during an afternoon's ramble.

In a like manner probably, but on a vastly more gigantic scale, the stream of materials on the 15th of July ran down the slopes of Bandai-san, dividing as it went into two principal branches.

The main branch flowed northward. Kobandai, it must be explained, sloped on the north towards the Nagase valley, in an unbroken descent; and, as the mountain burst on this side, the *débris* dashed with great violence down this northern slope in the direction of Hibara, 9 kilomètres away. One part of the torrent actually ran *up* the valley, toward the source of the River Nagase, burying on its way the three hamlets of Akimoto, Hosono, and Osuzawa. A part, however, of the pulverized earth ran *down* the valley; reaching Kawakami spa and submerging it to a depth of probably more than 40 mètres, it proceeded southward to Hinokuchi, 3 kilomètres farther down.

The other and much smaller branch took quite a different route, making an angle of nearly  $120^\circ$  with the main stream. It came down by way of Numanotaira, through Biwa-sawa, rapidly spreading as it descended, and dividing into three minor ramifications. The southernmost of these just reached the village of Miné, overwhelming



nearly one-half of the houses, with their inmates. Fig. 1 of Pl. XVII. is a view taken from the outskirts of Inawashiro, at a distance of nearly one kilomètre from the mud field, showing the village of Miné in front, and the avalanche (d) of rock and earth descending upon its prey. Fig. 1 of Pl. XVIII. is another and nearer view of this mud-field.

The combined volume of these two great streams entirely covered an area of 27 square miles, or 70 square kilomètres, with a solid sea of mud and rock, beneath which were buried all the features of the landscape, together with people, cattle, and other living things. The grey tint on Pl. XV. marks the area thus devastated.

Velocity of the  
descending materials.

The descending matter must have moved with great velocity. By some survivors it was described as having reached their vicinity almost instantly after the eruption. From several calculations, made by comparing the time of the explosion with the times at which the streams of *débris* arrived at different points, we roughly estimated the average speed to have been 77 kilomètres or 48 milés per hour. On its course the mud-stream must have swelled into great waves, as in a surging current. This is attested by eye-witnesses. The wave-like traces left on the sides of the hill (Pl. XX) show how the torrent surged upwards when it met any obstacle either obliquely or at right angles. In one case near Kawakami, the earth reached a height of at least 40 mètres above the general level on a hill facing the direction of flow and at other 40 mètres places a spur of the hill which the current struck obliquely caused an uprush of from 30 to 60 mètres. The general appearance of the present surface is one of extraordinary havoc and confusion, irregular lumps of earth being mixed up with torn-off trunks and branches of trees, fragments of timber, and stray boulders of huge size. In some places the matter has been largely admixed with water, and is treacherous to walk on.

In describing the phenomena of the earth and rock *débris*, the word *mud* has been frequently used by several observers, who speak of 'mud-stream,' 'mud-field' etc. We also have used the term above, but it must be explained, to avoid misconception, that we have done so for convenience only. Some commentators, indeed, have erroneously classed the phenomena with those of the 'mud volcanoes' of which we read in geological text-books that, while some have been known to throw up mud to a great height, in others liquid earth only oozes out quietly, and gradually forms an earth-ring round the crater. Such outbursts, however, are no more than moderate manifestations of subterranean energy, and are almost insignificant in comparison with the tremendous forces that destroyed Kobandai-san. Moreover, as far as our prolonged examinations went, there was no evidence of any discharge of mud from beneath. It is true that in the Nagase valley and other places there are now immense quantities of mud, but these became mud only after the eruption. During its descent, for example, a part of the *débris*, mingling with the waters of ponds and lakes in its course, doubtless acquired a muddy character and was thus assisted in its flow; and, again, that which reached the stream of the Nagase-gawa became admixed with sufficient water to thin it to the consistency of a paste. But by far the greater volume was comparatively in a dry state, being moistened only by condensing steam, and must have derived its fluid or semi-fluid properties from a rapid process of pulverization after the manner already described.

With regard to the secondary mud-stream that ran down to Miné, there has been a diversity of opinion. Some visitors imagined that there must have been more than one crater—that, in fact, the materials which destroyed Miné had a separate origin from the rest; and a cleft or depression at Hikage in Biwasawa, which, as viewed

from below, bore some resemblance to a broken crater-wall, was not unnaturally regarded as a proof of this assumption. But the spot, when examined by us, was found to be wanting as well in the characteristic features of a crater as in any appearance of its having been the origin of a violent volcanic outburst. If there had been such an outburst as to produce the vast quantity of matter that descended towards Miné we must have seen the crater or cavity from which the matter issued, unless indeed it were supposed to have oozed forth gradually after the manner of some of the mud-volcanoes already spoken of—a supposition, however, which is absolutely at variance with the observed facts.

The matter which descended toward Miné was really found, upon close examination, to be the loose red loamy soil that had formed the superficial covering of the flanks of Bandai, largely admixed with ash or dust, and boulders. The red colour of the soil was however concealed from view by the coating of grey-coloured “ashes,” 10-30 cm. in thickness, that fell especially abundantly down Biwa-sawa, the wind having been directed straight into that ravine during the eruption. At Numano-taira the accumulation of ashes was especially thick, and from thence it gradually lessened toward the lower part of Biwa-sawa. The mud field of Miné examined some time after was found to have been cut by the action of running water into numerous deep chasms often forming perpendicular walls and exposing the red loam underneath.

#### Conical Hills.

Among the various phenomena that constantly bewilder the eyes of visitors to the scene of the eruption, not the least striking are the numerous big boulders, some of them measuring from 5 metres to 10 metres each way, that are to be seen resting on the surface of the *débris* far away from the crater. These have evidently been carried along as part of the mud current, and not hurled through the air. Not less curious

are the quantities of small cones, varying from a few metres up to 15 metres in height, which are scattered here and there over the surface, standing out of the *débris* like so many miniature Fujiyamas. Fig. 1, Pl. XXI. and Pl. XXII will give some idea of these objects, as seen respectively from the northern and eastern side of Bandai. When closely examined, they are found to be disintegrated crumbling rocks, so affected by the agency of heated steam and corroding gases as to have lost their compactness. They are similar in character to the disintegrated rock commonly found near the crater-walls of active volcanoes. During and after their swift descent down the mountain sides, these rock masses have crumbled away, and the *débris*, falling around their bases, has assumed a conical shape by forming *taluses* around them. Fig. 2, Pl. XVIII. is a representation of one of the smaller of these hills found near the former site of the Kawakami spa.

On reaching the outposts of the mud field, no one could help being struck by the singular way in which the advancing stream of rock and earth seemed to have suddenly stopped, showing a vertical or nearly vertical face, a few metres high. It is apparent that the *débris* of rock and earth in their swift descent behaved like a fluid, but on nearing to the plain below they gradually lost speed and were ultimately brought to rest; the materials that followed, on account of their great friction and adhesion could not pass the limit set by their predecessors, and were piled layer on layer, thus forming a steep edge.

As is usual in all volcanic outbursts, large quantities of greyish-blue dust, or so-called ashes, fell during the eruption in the form of showers. Evidently much of this dust was produced by the mechanical trituration, during their flight through the air, of the rocks ejected by the explosions, which rocks, as already explained, had been rendered highly friable by the action of steam and gases. We found, in fact, that the dust was allied in character to the pulverulent matters com-

Volcanic dust.

posing the conical heaps of *débris* above described, and that both were derived from the andesitic rock which composed the mass of Bandai-san. Hence it is apparent that this dust or ash is quite different in character from the ashes that are usually ejected from craters in other volcanic eruptions, *e. g.*, that of Krakatoa in 1883. In such cases, the ashes are chiefly derived from molten magma, expelled by steam and mixed with fragments of the pre-existing rocks. They contain, therefore, more or less glassy matter, and are in fact pumiceous.

On the morning of the 15th, the wind blew from the W.N.W., so that the dust was carried towards the E.S.E., gradually spreading as it receded from the mountain. On the coast of the Pacific Ocean, which is 100 kilometres or 62 miles from the volcano, the width of the dust fall was 50 kilometres or 31 miles. In shape the dust-strewn area resembled that of partly opened fan, as shown by the dotted space on Pl. XXIV. On the land it covered a space of about 2,050 square kilometres or 790 square miles. How much farther it spread over the ocean we had no means of ascertaining.

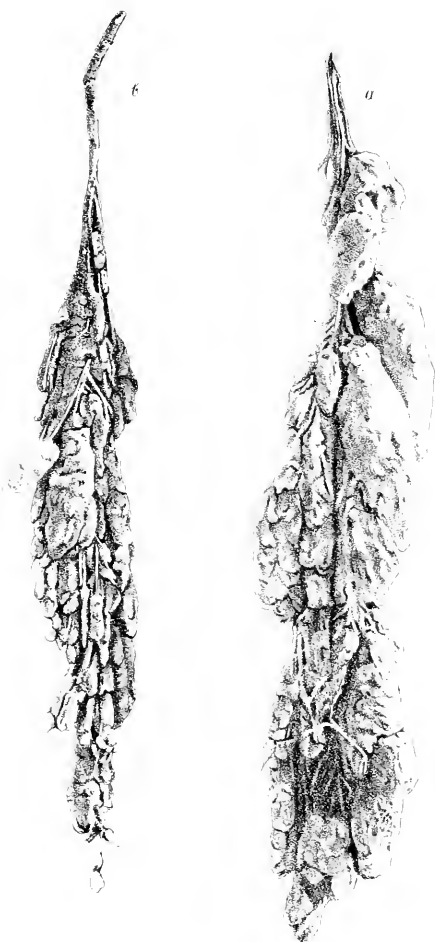
At the immediate foot of the mountain, especially toward the S.E., the dense cloud of dust produced pitchy darkness, which, however, did not last long; in the course of an hour the gloom had diminished to about that of the twilight of a rainy evening. But it was nearly 4 o'clock in the afternoon, or 8 hours after the eruption, before the dust wholly ceased to fall. The thickness of the deposit was about 0.3 metre on the south and east flanks of Biwasawa. In part the fall was in the form of a sticky, scalding mud-rain, produced by commingling of the dust with condensing steam. It inflicted terrible burns upon people exposed to it, and was the cause of many deaths. The ground also became so hot from this rain and the later dust that people had great difficulty in walking upon it. Every object was covered with a thick grey coating. Foliage, especially, that of the

*sugi* (*Cryptomeria japonica*), presented a very curious appearance, the

leaves, branches, &c, being clothed with a thick, pasty and highly tenacious deposit resulting from a mixture of dust with condensing vapour. A bunch of *sugi* (a), and a branch of Pine (*Pinus massoniana*), (b), thus covered are shown in the annexed illustration. In Shibutani and its neighbourhood, which experienced the full effect of the dust-fall, not a green thing could afterwards be seen.

Houses, paths, trees, fields, in fact all visible objects—wore a greyish hue. At Miharu a town 38 kilometres (24 miles) east of the volcano, the dust began to fall at about 9 a.m. and lasted till 2 p.m. During

this period the sky had a dim and cloudy appearance, as on a misty day. The ashes hardly covered the ground, but all the leaves of trees and vegetables were tinted grey. At the coast a very slight film only was perceivable on the house-roofs and foliage. Damage to plants and crops by the fall of dust extended as far as 10 kilometres from Bandaisan.



Hurricane.

The explosions were accompanied by terrible wind blasts, or *coups de vent*. In the parts most exposed to the fury of these blasts, houses were levelled to the ground and trees torn up by their roots. Everywhere, however, as might be expected, the fall was in a direction radially away from the forces of explosion, which was also the origin of these destructive and fearful gusts. In Pl. XV the area swept by the windblasts is shown by arrows, their heads pointing in the directions in which the trees and other objects fell. It was curious to see the manner in which one particular field of growing rice, on the southeast of the volcano, had been thus levelled by the wind. The slender stalks were laid flat upon the ground as evenly and regularly as if they had been combed down in parallel lines. Not a stalk lay across its neighbours. The heads of rice in one furrow covered the roots in the next furrow, and the entire field looked like the warp of some huge loom ready for the weaver's hands.

It would appear that the tremendous explosions of steam at quick intervals, lasting for about a minute, produced violent disturbances of the air, consequent upon the sudden radial expansion of the liberated volumes of steam. When a large piece of ordnance is fired grasses, shrubs and objects in the vicinity are overthrown by the sudden expansion of the gaseous products escaping at the muzzle, which, displacing the air, imparts to it a forward impulse and violent vibratory motion. The eruption of Bandai-san may be aptly compared to the firing of a tremendous gun—such an one, however, as can only be forged by Nature.

Places screened by hills and mountain sides escaped. Marumori-yama, situated near the mouth of the crater, and fully exposed, received the severest damage. This hill, which was formerly covered with a thick forest, now presents a most melancholy appearance, the few trees left standing being as naked as telegraphic poles. The

levelling of houses and shattering of forests are of common occurrence in great storms. But on this occasion the destroying tempests especially near the crater were something more than atmospheric, consisting besides of heated blasts of steam and air, thickly mixed with dust and rock-fragments fierce enough to crush the trees and to strip them not only of branches but even of their bark, and withering, scoring, and scorching everything in their course.

Some of the most terrible effects of these tornadoes were wrought in the Biwa-sawa and its vicinity. Originating at the old crater, Numano-taira, this glen, the deepest and widest in Bandai-san, descends directly and in an unbroken line to the villages Shibutani and Shirakijō. Notwithstanding the comparatively great distance of these two villages from the crater, the wind-blasts were impelled towards them, down the Biwa-sawa, with prodigious force, and wrought havoc from which places a little out of the direct course of the wind were happily exempt. In the woods on the S.E. slope of Akahani-yama and on the west side of Biwa-sawa, the effects of the storm were especially striking; trees with a diameter of more than a metre had been laid prostrate on the ground in thousands; and a forest was thickly encumbered with fallen trees. Estimating the probable velocity of the wind from the effects produced in this locality, Mr. Y. Wada, of the Imperial Meteorological Observatory, thinks it can hardly have been less than 40 metres per second, or about 90 miles per hour. Here as everywhere else, the trees fell with their heads pointing away from the crater, showing clearly that the wind radiated in straight lines from its origin. There is no evidence of whirlwinds or eddy movements of any kind. The cause and effect of the wind in this locality deserve special attention, for which a brief topographical examination is first needed. South-south-west of the former site of Kobandai stands the massive peak of Ōbandai rising to a



height of 1,840 metres (6,035 ft.) above the sea, and east of it, Kushigamine, the third peak of the Bandai group, with an altitude of 1,622 metres above the sea. Between them is Numano-taira, the large flat basin of the old crater, with 1,311 metres above the sea-level. At the base of the huge U shaped aperture formed by the slopes of the two mountains the Biwa-sawa begins to descend. Fig. 1 on the wood-cut shows roughly the relative positions of the peaks and the old crater in plan, and Fig. 2 shows a vertical section through A B.

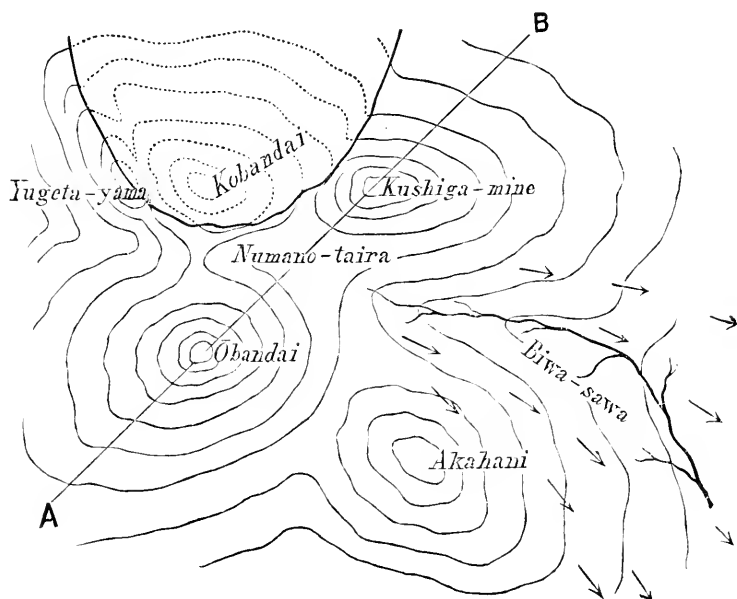


Fig. 1.

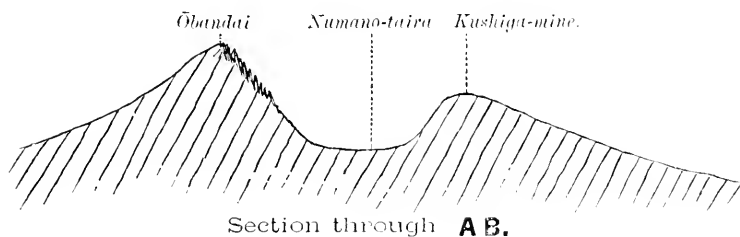


Fig. 2

Now, when the steam emancipated by the eruption suddenly expanded and drove before it the surrounding air, a portion of this air

and steam must have been forced through the U shaped aperture aforesaid. Emerging therefrom at a very high velocity, it swept the whole Biwa ravine which preserved more or less the U shape downward, and ravaged the eastern half of the inferior peak Akahani. The evidences of this were clearly apparent on the ground itself, the dividing lines between the wind-swept area and the comparative calm which prevailed on either hand having been so sharply defined that the belt of levelled forests and ruined houses was separated by a few metres only from the unharmed areas to the right and left of it. Nothing new can be claimed for this phenomenon, which is a well-known characteristic of certain storms, especially of whirlwinds having their apex near the earth's surface. But its definition on this occasion was interesting and well-marked.

Attempts have been made to associate these particular *coups de vent* with the moderate northwesterly breeze that prevailed at the time. But it is obvious that, though this wind determined the direction of the dust-cloud in the higher regions of the atmosphere, it must have been powerless to contribute sensibly to those intense blasts which descended the Biwa-sawa and swept over the region at the base of the mountain.

Next let us examine how the wind behaved on the other sides of the volcano. On the east, as before described, Kushiga-mine formed a screening wall which deflected the course of the hurricane; on the west, Yugeta-yama, the part of Kobandai that remained undestroyed, and other ranges of hills arrested the expanding steam and the rush of air, and saved the forests behind. But on the north, there being no obstruction in that quarter, to which moreover the discharges were directed at an inclination to the vertical, the effects were probably tremendous, as was evidenced by the condition of Marumori-yama. Indeed, every spot of the ground to the north of the crater, for several

kilometres, was utterly turned 'topsy-turvy' and every land-mark obliterated. For this reason it was impossible to tell the real state of things in that quarter.

It is well known that at volcanic outbursts the immense volumes of steam, suddenly expanding occupy a much larger space than that of the original bulk. This sudden expansion cools the temperature of the surrounding atmosphere and lowers its pressure. Moreover, the steam in part condenses. To fill the partial vacuum thus produced, and to equilibrate the reduced pressure, there follows an inward rush of air towards the crater. The strong winds commonly described as a feature of volcanic eruptions, are probably due to this cause, and the same thing doubtless happened to a certain extent in the case under discussion. But the fearful blasts that wrought such havoc in the forests and villages on 15th of July certainly were not counter currents of this class, however strong these may have been. It was the gusts *from* the volcano that in this instance wrought the real havoc.

A whirlwind is described as having occurred during the volcanic eruption\* in the Island of Sumbawa, in Java, on the 5th of April, 1815, when, soon after the ashes began to fall, a violent whirlwind ensued, which blew down nearly every house of Sangir; it tore up by the roots the largest trees, carrying them into the air, together with men, horses, cattle, and whatsoever came within its influence. The whirlwind lasted about an hour. It is not stated in this account, however, how the whirlwind was caused.

Conical holes.

Several visitors to Baudai, ascending from the south sides and approaching the summit, had their attention attracted by numbers of curious conical basin-like holes, evidently the fruits of the late eruption. Their size varied from 2 to 3 metres in diameter and from

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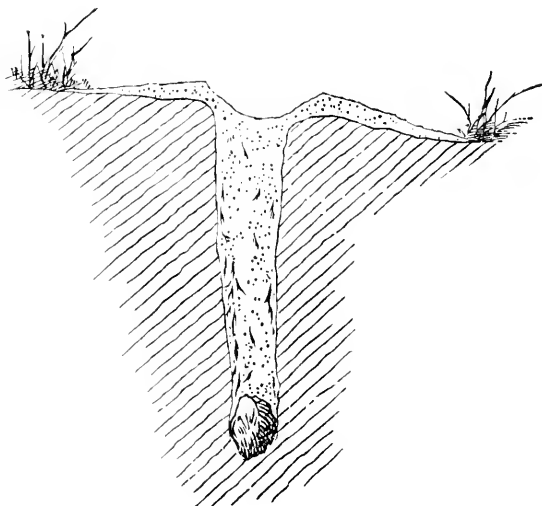
\* Lyell's Principles of Geology, 12th Ed. Vol. II, p. 104.

a few decimetres to more than a metre in depth ; and they were generally wider at the mouth than at the bottom. They were found in thousands in the neighbourhood of the crater, as well as on the extensive slopes of Ōbandai and Akahani, a few kilometres away.

As to the origin of these holes, though they were not perhaps a very important phenomenon of the eruption, it calls for a brief discussion, because it has been the subject which has caused a good deal of diversity of opinion and some lively controversy. First of all, they were regarded by some witnesses as miniature craters, each formed by a small explosion of steam. This supposition arose from the facts that several of the holes had the appearance of having been formed by ejections from below the surface, and that in some cases steam had been seen issuing from the holes. But the latter phenomenon was only to be seen near the solfatara adjoining the new crater, from which steam had been issuing for ages ; and the appearance of fresh steam-jets in that locality would not be surprising after the convulsions caused by the catastrophe of the 15th of July. Even, however, if it be allowed that there were a few slight steam explosions in this immediate vicinity, it is, in our opinion, impossible to extend any such hypothesis to the innumerable holes of like appearance that were scattered over the extensive and distant slopes of Ōbandai, Akahani &c. Prof. J. Milne on the other hand, regarded the cause of the holes as seismic, but not volcanic, that is to say, he concluded that earthquake-waves produced at the time of the eruptions, and passing through the soil, caused sub-surface compression and distortion and thereby ejected earthy matter from below, by the spouting action of water. We shall show farther on that the above theory can hardly be applied to any but a few marshy spots in Numano-taira, to be presently described.

Others, again, contend that the holes were caused by the fall

of stones projected into the air from the crater. This we take to be the true explanation. Puzzled at first as to the origin of the holes, but determined to investigate it fully, we dug a number of them open. Thereby our doubts were soon cleared up. We found imbedded in the ground brittle and freshly fractured stones that had apparently been shot forth by the volcanic outburst. Where the soil was rocky, fragments of similar stones were scattered all about. In one case we obtained very decisive evidence. A stone was discovered in the soft loamy soil formed by the decomposition of andesitic rocks, at a depth of nearly 2.5 metres below the surface. The stone was angular in shape, measuring nearly 0.5 metres each way, and showed a freshly broken surface. Leaves of bamboo, dwarf pine, and creeping surface plants had been carried with it into



the soil. These were much packed and crushed, but were still fresh and green when dug out. On closely examining the hole we found that, although more or less funnel shaped near the surface, it had been sharply cut through in a tubular form, by the passage of the stone which lay at its bottom. The original tubular passage was, however, filled up by loose detritus mixed up with ashes, and here and there with shrubs and bamboo twigs, while the surrounding soil was a compact native red loam. The main features of this hole are shown in the accompanying diagram.

It was stated before that the steam ascended perhaps 1,280

metres (4,200 ft.) above the crater. If stones were thrown up to the same height as the steam column, their initial velocity must have been 158 metres per second, and this may be roughly taken as the final velocity with which, on falling down, they would reach the ground. But if we suppose that the steam and stones reached to double or treble the above height, which is not improbable, the initial velocity becomes 224 and 274 metres per second respectively. The velocity needed for penetrating a soft loamy soil to a depth of 2·5 metres would be between 300 metres and 600 metres per second, according to the values of coefficients we take, but in these calculations, as we are using several more or less arbitrary assumptions we cannot take them as a sound basis for discussion.

It seems not strange, however, to find that the basin-like holes wearing those appearances of having been blown out from below have led to the theory of their formation by internal explosion. Stones striking the ground with great force would make holes of larger diameters than their own by throwing the surrounding earth outward. Again, if the fall of any stone take place at a spot where there are rocks on or near the surface of the ground, the concussion will shatter the falling stone and at the same time blow up the adjoining soil, thus producing the appearance of an eruption. We have witnessed great number of those cases on Ōbandai and Marumori-yama.

The inhabitants at the base of the mountain noticed among the rising steam small and large white objects ascending and descending like shooting stars. At one time, they were so numerous that they almost looked like white rain. It seems very probable that these objects were stones ejected from the crater.

That large fragments of rocks are hurled into the air during volcanic eruptions is a matter of common experience. But that they have left their traces upon mountain sides in the form of conical holes

has not, as far as we know, been recorded; perhaps it has never been observed. It must not be forgotten, however, that there would have been no such holes on Bandai-san if there had not been the thick layer of soft loamy soil to receive the falling rocks.

Mr. E. Odum, of the Toyō Eiwa Gakko (Oriental English school), Tokyō, made a thorough investigation of the origin of the conical holes. He went twice to Bandai, the second time for the sole purpose of examining the holes, and his observations on the spot were very complete. Indeed, we consider that the facts and proofs brought forward by this observer must be held to settle the question. In a paper read last autumn before the Seismological Society of Japan, Mr. Odum showed that hundreds of thousand of stones have been hurled into the air from the crater. People were wounded and forests were shattered by them. Sometimes fragments of rocks of considerable size were imprisoned on broken trunks of trees. Native mountain rocks had on their upper surface marks and scars made by the stone projectiles. On excavating some of the holes, Mr. Odum found in them imbedded stones, some of which weighed 4,000 lbs, or 1,814 kilogrammes. Under these stones grasses, weeds, leaves, branches, and other kinds of vegetable materials were sometimes discovered, often bruised and shattered till they had the appearance of having passed between rollers. Many of the stones fell in a slanting direction; they were not lodged in the centres of holes, but almost always to one side, that is, the side away from the crater. The earth round the imbedded stones was solid and native—no sign of their having been disturbed by explosive action or the like was found. The whole mountain, the top as well as valleys, was covered with these pits as if it had had a heavy attack of smallpox. To suppose, continues Mr. Odum, that the holes were formed by the spouting action of subterranean water, as is held by some authorities, we must assume

that the whole mountain was literally made up of water, and inundation must certainly have resulted from the creation of such immense number of water jets in a short space of time. Mr. Odlum made numerous measurements of the pits; they vary from a few feet in diameter to over thirty feet, and from 2 to 10 feet in depth.

Lieut. Y. Nakashima, of the Army Department, who surveyed the volcano after the eruption, and who, from the nature of his work, acquired an intimate knowledge of the whole area is in entire accord with our opinion as to the origin of the pits.

Notwithstanding these evidences, however, the conclusions arrived at by us and other workers have been freely criticized, and doubts have been thrown upon them. Prof. J. Milne of the Imperial University, dissenting from our views and those of Mr. Odlum, believes that the cause producing the holes was seismic in character—to wit, the severe earthquake that accompanied the eruption. He quotes Robert Mallet in support of the hypothesis that they were produced by the spouting action of water from beneath, resulting from seismic compression of the substance of the ground. Similar pits, he says, were made in the great Calabrian earthquake of 1783, and they were specially investigated by a committee sent from the Royal Academy of Naples. These gentlemen also dug into holes, Prof. Milne continued to say, but we do not hear of their having found any boulders. We (the authors of the paper) think that the Neapolitan scientists did not strike into boulders, simply because the pits in the Calabrian plain were not formed by falling stones, which was the case on the slopes of Bandai. It was also argued that like phenomena were observed in the Charleston earthquake of 1886, when sand and muddy water were ejected, making more or less conical holes. But, as far as we understand the matter, the formation of holes during destructive earthquakes by the spouting of water or sand is limited to plains and



watery places. In the case of Bandai, such formation might have occurred in the marshy plateau of Numano-taira and perhaps in other limited areas among the valleys. But we regard it as impossible that ejections of water or soil, produced by seismic action, could have occurred over the great area covered by the pits under discussion on the rocky summits and steep slopes of Bandai and Akahani. It is true that in Numano-taira large round or elliptical holes were made, some of them having diameters of over 7 metres and being left partly filled with water. But, though it is not impossible that these particular holes were produced by seismic action, the more probable explanation is that the falling *débris* from Kobandai covered the ground to a great thickness, burying under it forests and ponds; and it is natural to expect that in this great field of loose *débris* depressions would be formed here and there by the falling in of the superincumbent layers. We ourselves observed some of the holes gradually increasing in size by the falling in of their margins.

In their paper read before the Seismological Society of Japan, Professors C. G. Knott (Tōkyō) and C. Michie Smith (Madras) contend that by far the great majority of holes are due simply to the uprooting of trees caused by the hurricane. This they regard as especially true of the region to the south-east of Ōbandai. They argue that if the countless numbers of holes were due to falling stones a great many other stones must surely have fallen on the same ground with velocities too small to make holes. But of these other stones there is no evidence. Besides they doubt if it is dynamically possible for a falling stone to make conical holes of the size and form described so fully by Mr. Odium. For a stone to bury itself several feet in the ground and at the same time make a violent "splutter" is not, they think, at all credible. After the undoubted effects of uprooting of trees, and of landslips in a volcanic soil violently shaken

by an earthquake, are given their full weight, they consider that a very limited number of holes will be left to be explained by falling stones; and that these holes will be either flat basin-shaped bruises or tubular cavities of comparatively small diameter.

We shall not stop to answer all the points criticized by Professors Knott and Smith as we think we have already spoken enough on the subject. It is quite true, we admit, that conical holes were produced by uprooting of trees in forests; indeed we saw numbers of such holes near the upturned roots, especially on Miné-yama. As the origin of these there could be no doubt. But by far the greatest numbers of holes were found on bushy hills, on grassy slopes, in rocky glens, or in regions that were not occupied by forests, and on ground where the trees still stand uninjured. Such are the holes which we believe to have been formed by falling stones, and to which we have been referring throughout.

The fact that the bamboo leaves which we discovered under the stones, and which we brought back to Tōkyō, were comparatively uninjured was much criticized by saying that, if they had been forced into the ground by the boulders, they must have been more severely damaged. Those which we discovered were, however, originally much folded and packed, while the specimens collected by Mr. Odum were crushed to a much greater extent.

Mr. Ōtsuka, a school-master in Hibara, who kept a diary of the weather and other matters, told us that there were slight shocks of earthquake on the 8th, 9th, and 10th of July. At about 3 o'clock on the afternoon of the 13th there were occasional shakings of the ground which were also felt at Inawashiro. Between 3 and 4 o'clock on the afternoon of the 14, i. e., the day preceeding the eruption, quite an extensive earthquake occurred in the neighbouring provinces, but although it was felt in the Bandai-san district its origin was far away

Earthquakes.

to the west near the coast of the Japan Sea.

On the morning of the 15th, at a little after 7, a feeble earthquake occurred, but it was so slight that many failed to notice it. After half-past seven a severer shock ensued, lasting nearly 20 seconds. This was followed soon after by very violent convulsions of the ground; houses rocked and swayed, furniture fell down, and the frightened people felt the ground heaving beneath their feet. It was reported that the nature of this earthquake differed from that usually experienced, in that vertical motions greatly predominated. The shock was a long one, lasting, according to some accounts, for fully a minute. While it was still in progress the eruption took place. Considering the fierceness with which this earthquake shook the immediate vicinity of the mountain, it is remarkable that the intensity was very rapidly decreased as the seismic waves were propagated into the surrounding region, and the shaken area was limited to a radius of, roughly speaking, about 48 kilometres, or 30 miles. This may be accounted for by the fact that the origin of the shock was rather near the surface. On Pl. XXIV the boundary of the area shaken by the earthquake is shown by a thick elliptical line.

Volcanic eruptions are generally accompanied by earthquakes, and the shocks on this occasion prove that sudden expansion of steam and breaking up of the earth's crust may produce seismic vibrations. The efforts of the pent-up steam, struggling to force its way through the superincumbent masses, at last succeeded in bursting through a weak point, the explosion being accompanied by violent convulsions of the ground, that were propagated as seismic waves.

On the 20th of July, at 11.50 a.m., a feeble shock was experienced. Other minor shocks are said to have subsequently occurred.

To see whether the ground in the crater was perfectly quiet after the eruption, we took with us a delicate though somewhat

roughly made pendulum tromometer, which had a magnifying power of 27. We first set it near a fissure from which powerful jets of steam were issuing with hissing sounds. In that position the instrument indicated very feeble vibrations of the ground, which were doubtless caused by the issuing jets. We next set it in Nakanoyu, near our camp, and made daily observations. As far, however, as the magnifying power of the instrument enabled us to judge, there was no evidence of lingering earth-tremors. And it would seem from this that the forces which produced the explosion had been completely expended in blowing away the mountain, and that the region had already become seismically quiescent.

Near the volcano the detonations in the earlier part of the eruption were described as deafening. Though rapidly lessening in intensity, the thundering noises lasted for nearly an hour, and did not entirely cease for several hours. The area over which the sound extended was very much smaller than might have been expected. From the tabulated reports at the end of this paper, and from other sources, it appears that the sounds of the explosions were not heard distinctly at a greater distance than 48 kilometres or 30 miles to windward of Bandai-san, though to leeward they were audible at the Pacific coast, a distance of 100 kilometres or 62 miles. How much farther they reached, over the sea, we had no means of ascertaining. Mr. K. Nakashima, of the Geological Survey, told us that, while he was ascending Kinboku-san in the island of Sado, on the morning of July 15th, he heard dull rumblings which were supposed at the time to proceed from the firing of heavy guns in the neighbouring harbour (Report 21). Sado is in the Japan Sea, nearly 161 kilometres or 100 miles west from Bandai-san, and therefore to windward of it. Possibly, however, the sounds heard by Mr. Nakashima came from the volcano. It was also reported that peculiar detonating

Sound.

sounds were heard on the same morning in Takai-kori, in the Province of Shinano, distant about 164 kilometres or 102 miles southwest from Bandai-san. The barograph in the Imperial Meteorological Observatory in Tōkyō, which is 212 kilometres or 132 miles south of Bandai, was not affected. The magnetometer in the same Observatory also gave no record that could be regarded as an effect of the eruption.

While we were staying on the mountain we often witnessed the fall of large masses of the perpendicular crater wall, which, coming down from great heights with stupendous force, were smashed into thousands of fragments and descended with whirlpool-like movements to the lower levels. These slips produced terrible rumblings, which resounded throughout the crater, and were also heard far away. By the already panic-stricken inhabitants of the neighbouring villages these repeated noises were regarded with consternation as tokens of a further volcanic outbreak, and it was weeks before they became pacified and assured as to the real cause.

Lightning.

From the ascending columns of steam and ashes vivid zig-zag flashes of lightning were seen to dart forth, and were accompanied by loud roars of thunder. These phenomena, observed from several points around the mountain, may be regarded as resulting from the discharges of frictional electricity which, as is well known, are liable to be brought about in volcanic explosions when steam at high tension escapes through a narrow orifice, and collides with the surrounding air and the more solid ejectamenta.

Sparks.

While the main eruptions were going on, the people in Inawashiro and the neighbouring villages saw through the densely falling ashes innumerable vivid sparks of fire on the slopes of Ōbandai and Akahani, at considerable distances from the crater. These sparks were quite different in nature from lightning, presenting rather an appearance as of the firing of a vast number of guns. The probable

explanation of the phenomenon is that sparks of fire were produced by stones and rocks striking against each other in the air or falling on a rocky bed. Fragments of rocks are scattered in abundance on the slopes of Ōbandai, but we could discover nothing to lead us to believe that there had been combustion or any other heat manifestations. Sensational newspapers in their accounts of the eruption spoke of lurid flames, of a blazing crater and other terrors all probably founded on the peasants' reports of the sparks above mentioned. It very rarely occurs, however, in volcanic eruptions that flames are produced by the burning of gases issuing from craters. Sir W. Hamilton, in describing the Vesuvian eruption of 1779, noted that large vitrified masses (bombs), falling upon the ground, broke into many pieces, and set fire to combustible objects. In this case, however, the fire was produced mainly by the heat of the fused masses, whereas at Bandai the sparks were caused by impact. On the other hand, at the time of the great volcanic eruption of Tarawera, New Zealand, in 1886, the falling sand was said to have been hot and to have set the trees on fire.\*

As regards unusual optical phenomena, we have heard of one or two only that seem to have been connected with the eruption. Anything like the twilight-glows, haze, etc, which were such important features after the Krakatoa explosion, could hardly be looked for in this case, which, though exceedingly remarkable in many respects and interesting in the highest degree, was very much inferior in magnitude to the gigantic eruption of 1883 in the Sunda Strait. However, an observer at a place about 87 kilometres or 54 miles E. S. E. from Bandai noticed towards evening on the day of the eruption sparkling rays of red light issuing from the clouds (Report

Optical  
phenomena.

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\* Nature, Vol. 34, 1888, p. 392.

15). Another, living in a village S. S. E of the mountain, saw with mixed fear and delight how the rising columns of steam from Bandai-san, refracting and decomposing the light that fell upon them, produced a most beautiful display of variegated colours (Report 8).

Premonitory  
signs.

It has been often asked whether there were any premonitory signs of the explosion. It is certain that slight shocks were felt on previous days, as well as half an hour before the outburst. But beyond this the evidence is vague. Some persons vouch to having heard mysterious rumbling sounds in the mountain prior to the eruption. Again, some animals are said to have shown alarm. No doubt before an explosion of such magnitude as that of Bandai-san, earth must have been in a seismically sensitive condition, and certain animals which are known to be highly susceptible to even minute earth-tremors may very well have been frightened on this occasion. Some well-waters are also said to have diminished in flow. None of these alleged facts, however, have been clearly established on the evidence of trustworthy persons. On the other hand, Mr. Tsurumaki says in his letter (page 105) that the bathers at Nakanoya did not observe any abnormal changes in that spring, though it is situated on the very edge of the new crater. It would be interesting to know exactly how Lake Inawashiro behaved before the eruption. The water level of that lake is systematically recorded at two places on the shore, for purposes of irrigation. But we were unable to learn, either from conversation with Mr. Akiyama, who keeps the record, or from the entries in his books, that there had been any sudden fluctuations of level during the two months preceding the catastrophe. In reports lodged at the Fukushima Prefecture it is stated that the river Nagase, the Lake's chief feeder, decreased its flow from April or May, and that the water level of the Lake on the 1st of July was one foot lower than on the corresponding day of the previous year. A captain

of a steamboat running on the lake told us that his vessel, anchored close to the shore, was moved outwards nearly 0·6 metres by the disturbance of the water. Though this disturbance occurred almost simultaneously with the eruption, we are disposed to agree with the captain in believing that it was a result of the earthquake immediately preceding it.

On the whole, the only premonitory signs that were really trustworthy were the slight shocks which occurred on previous days and half an hour before the eruption, and no implicit faith can be placed on the slight testimony in favour of other warning symptoms.

Volcanoes have often been described as one of the principal restorative agents in counteracting the denuding action of water that tends to bring the surface of the earth to a level. In the late eruption of Bandai, however, the effect was destructive and not constructive. The materials which had accumulated in past ages gave way, and were thrown down from a higher to a lower level in less than an hour; the effect of this being analogous to a gigantic land-slip. In this way, considerable changes have been wrought in the topography and contour of the adjoining districts. How the torrent of earth and rocks devastated an area of some 70 square kilometres (27 square miles) has already been described in the preceeding pages. The general effect of this spreading out of *débris* was to effect the leveling of the general contour; all the surface ravines and gorges, being entirely filled up. The northern side of Bandai was before the eruption, an undulating grassy plain—the ‘Hara’ so characteristic of volcanic districts in Japan—drained by the river Nagase, and dotted here and there with some straggling hamlets. Professor J. Milne who visited this part of the country several years ago described it as consisting of grassy slopes without any exposure of rocks. The descending deluge of *débris* pouring across Ōbudaira, as the northern

Change of topographical features.



slopes of Kobandai are called, engulfed all the familiar land-marks, and converted the district into a desert waste. Thousands of conical mounds, large and small, have been formed on this vast sea of mud,—giving a quite unique appearance. Not only have the depressions been filled up, but the higher ridges have been reduced in height. The deluge of earth *débris* in its quick descent, impinging on the prominences that were lying in its way, have actually leaped over them, scraping off the outer-crust of the soil, and exposing the native rocks beneath, as a glacier might have done. In other places the torrent of rocks dashed against the hill-sides and scoured them away. Large quantities of mud carried along with rock, *débris*, and boulders, have penetrated deep into every recess of the valley. The largest and longest of the mud streams is that which flowed down the slope of the river Nagase to the Kawakami spa. Near the village of Hibara, and the former site of the little hamlet of Hosono, the peaty deposits which had accumulated in the marshy ground have been ploughed up. Large clumps of red loamy soil mixed up with half carbonized wood and grasses are found turned up or standing in an irregular state of contortion.\* Nowhere could the scouring action of the mud torrent be better realized than in these parts.

The official reports relating to the area of land buried under mud are given in the following figures. The loss of property involved is said to have been immensely great. There is absolutely no hope of recovering or reclaiming the buried land.

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\* Among this turned up peaty deposit, an interesting occurrence of *vivianite* may here be noticed. The formation of this mineral seems to have been brought about through the agency of organic matter. It is found in the form of a beautiful azure-blue coloured, fine powder, filling up the spaces especially of the rind and core of the fragmentary branches of half carbonized wood belonging to some Coniferous tree. The spot, however, where we have witnessed this phenomenon, being situated just on the southern front of Hibara lake, must have now been submerged under water.

	Square kilometres.	Square miles.
Cultivated land.....	0·82 .....	0·32
Plains .....	22·60 .....	8·73
Mountains and forests .....	41·93 .....	16·19
Rocky slopes and glens .....	5·36 .....	2·07
<hr/>		
Total .....	70·71	27·31

It is highly probable that, though at present the new land appears like a desert waste, the growth of vegetation will take place in a comparatively short time favoured by the admixture of the fertile volcanic products.

One of the most striking secondary effects of the eruption is the formation of new lakes, due to the damming up of the river Nagase and its tributaries by the *débris* of the shattered mountain. These lakes are four in number, and are shown on Plate XV. They may be conveniently called Osuzawa, Hibara, Onogawa, and Nakatsu (or Akinoto) lakes, after the tributaries of the Nagase to which they are respectively due. The largest of them is Hibara lake, measuring nearly 4 kilometres or 2·5 miles from north to south, the breadth being nearly  $\frac{1}{3}$  of the length. These lakes continued for many months to increase in size, through the gradual accumulation of water within the newly formed barriers of *débris*. Thus it was not till fifteen days after the eruption that the village of Onogawa became covered with water. The inhabitants then fled to Hibara; but were subsequently driven out from that village also as the waters gradually rose.

Beside these four large lakes, there are scattered among the mud-field smaller patches of water caused by the accumulation of rain water, or formed by the smaller streams on the mountain-sides. These lakes will continue to increase in size until the water comes to the level of the lowest possible outlet from the hemmed-in basin. The

issuing stream will soon cut deep passages through the loosely cohering *débris*; and it is to be expected that sudden yieldings of some of the barriers will take place. Hence will result a rush of escaping water accompanied by violent floodings in the lower courses of the stream. It was thus that certain villages and cultivated fields were flooded when the Nagase-gawa burst its lowest barrier, which immediately after the eruption quite stopped the flow of that river into Lake Inawashiro. Because of the loosely compact character of the *débris*, the configuration, size, and number of these lakes will alter greatly as time goes on.\*

On the 13th of April of this year (1889) about 6 p.m., a large portion of Onogawa lake was suddenly drained, and the torrent of water rushed through the mud-field, carrying mud, pebbles, and boulders to the lower levels. The embankment newly erected at Nagasaka and other places to protect from inundation, was destroyed, and the water spread out into the cultivated fields adjoining the district of Inawashiro. Considerable damage was done to bridges, and roads, but fortunately the houses and inhabitants escaped.

New lakes or ponds are also being formed within the crater, by the condensing steam and the rain water. The waters of these lakes contain much soluble matters and some of them are hot. But as the crater-bottom is set in a sloping position, an accumulation of water to any considerable extent cannot take place.

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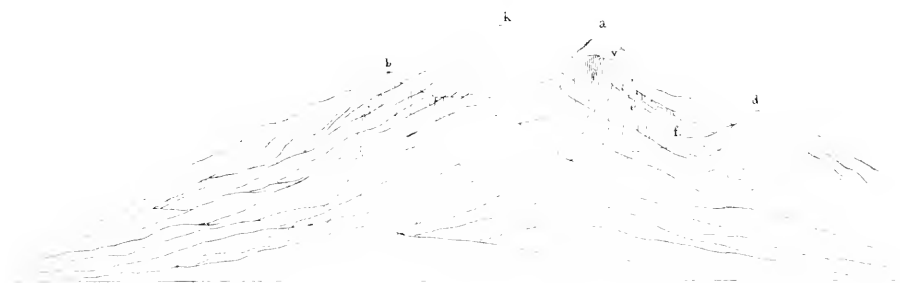
\* As this is passing through the press, we are able through the kindness of Professors C. G. Knott and C. Michie Smith to call attention to the remarkable changes in the region under consideration. These gentlemen visited Bandai towards the end of May, 1889. They report that Hibara and Ōsawa lakes have united into one huge lake which forms the most prominent feature in the landscape. The other lakes are comparatively small. Of particular interest, also, are their observations on the erosion of the new earth by the action of running water. Thus the comparatively small stream that ran down Biwa-sawa has cut out of the new earth a deep V-shaped gorge, in many places attaining a depth of 40 or 60 meters. At these places the stream has not yet cut down to the original surface. Their observations are to be published in full in the Transactions of the Seismological Society of Japan.

The distant view of Bandai as seen from certain directions has been altered by the destruction of Kobandai. When viewed from its south side, however, e.g., from the town of Wakamatsu, the mountain apparently does not show any sign of great change; the prominent peak of Ōbandai entirely screening from view the place of devastation. Before the time of the explosion, the top of Kobandai, when seen from this side, was presented as a small prominence on the left side of Ōbandai. Fig. 3, Pl. XXI, is a sketch taken soon after the catastrophe. The dotted outline in this figure is the original form of Kobandai, which has now entirely vanished, and in its place columns of steam are seen rising.

The most magnificent sight is presented to view when the mountain is seen from the northern side, where the full force of the explosion may be best realized. The newly opened explosion-crater (Fig. 1, Pl. XVI, Fig. 1, Pl. XXI) is fully disclosed; the wreath of steam rising from its central linear fissures like a cumulus cloud. The sound of the evolving steam is distinctly heard from the village of Hibara fully 9 kilometres distant, evidently due to the fact that the crater opens unobstructed on this side, and is backed by perpendicular walls. On the right side we see a jagged rocky precipice, the remains of Yugeta-yama which formed a small prominence on the flank of Kobandai. The extensive waste of mud and rocks, gradually sloping from the crater toward the plain below with its curious conical rock-hills and bared mountain sides, gives a most vivid and awful impression to the mind of the vastness of the devastation.

It would have been very interesting to compare the original form of the mountain as seen from the north with its present form. But as we have already stated this part of Bandai was very scantily peopled, and hardly ever visited by scientists so that there seems to

exist no sketch or photograph showing an accurate outline of Kobandai before the explosion.



The accompanying figure shows the probable appearance of the mountain previous to the eruption ; this reconstruction of the original scenery being made from the sayings of the people who knew the mountain well, and from general topographical considerations. The dotted line in the figure is the present outline of the mountain, viz., the reproduction of the outline as shown in Fig. 1., Pl. XXI., reduced to one half.

The prominent peak (*k*) is intended to be the restored form of Kobandai or Little Bandai, which when seen from this side must have looked more massive and prominent than Ōbandai, or Great Bandai (*a*). To the west of Kobandai immediately over Kamino-yu (*c*), is seen a small prominence known as Yugeta-yama (*y*), which was half destroyed, forming now a very rugged precipice as already mentioned. It is to be observed that the fumarole of Kamino-yu is situated within a small ravine having a very steep side-wall, probably itself a small explosion-crater formed at some former period.

Four hamlets—Osuzawa, Hosono, Akimoto and Kawakami—have been completely buried beneath the rock and mud along with their

inhabitants and cattle, leaving no visible trace of their former existence. Even the few survivors who escaped death by their timely absence from home could not tell where their villages had been, as every land mark was entirely obliterated. Seven villages—Miné, Nagasaka, Shibutani, Shirakijō, Hinokuchi, Myōke and Ojigakura—were partially destroyed either by the avalanche of earth or by the storm of wind and rubbish, and were thickly covered by ashes. The loss of life and cattle was also considerable. The destruction of the three spas in Bandai-san, viz., Kaminoyu, Nakanoyu and Shimonoyu, has already been mentioned. In all, 166 houses were either totally or partially destroyed.

The total number of lives lost amounted to 461. The principal cause of the death was the deluge of rock and mud *débris*. In some instances people were buried under their roofs, having no time to escape; but in the majority of cases they were caught in the swift torrent of mud while endeavouring to reach some safe place. Many were also battered by falling stones. A most remarkable incident occurred in the village of Nagasaka which had 168 inhabitants, and was attended with a serious loss of life. This village being situated behind Kushigamine was effectually screened from the direct attack of the mud current. On the morning of the eruption when stones and earth began to fall upon their roofs, accompanied by appalling noises and earthquakes, men and women rushed out of their houses leaving the old and young behind, and attempted to cross the valley of Nagase in order to reach the opposite hill which they thought to be a safer situation. They had only to travel not more than 500 metres across, but of ninety-two who thus fled, not even one reached the other side safely.

Out of the total of 461, only 117 corpses were recovered, all the remaining bodies being entirely buried under the mud. The

number of wounded was 70 in all. They were mostly burnt and scarred by the hurricane of hot ashes and falling stones. The wounds in several cases were very peculiar. Fragments of rock projected violently from the mountain, impinged upon the unfortunate people like grape-shot. The sufferers were tossed about and often felt as if they were lifted up bodily into the air; at the same time their clothing was torn off, even to the under-garments. In many cases bits of stones were found sticking in the skin and flesh of the victims, and were with difficulty extracted. In one case the skin was completely peeled off from a woman's skull, probably torn off through entanglement with trees or other objects which were being violently hurled along. The mere contemplation of such experiences is horrifying.

Bandai-san  
after eruption.

The winter climate of this part of the country is very severe. Snow begins to fall in the middle of autumn, so that in winter travellers are rarely seen, and the peasantry hardly ever venture far abroad. The result is that very little knowledge can be obtained about the behavior of the volcano during the cold months. Mr. S. Kobayashi, a school-master at Inawashiro, who helped us in various ways during our stay in Bandai-san, has, at our request, very kindly given us the following information :

Letter dated Nov. 7th, 1888.—Since the eruption, even in bright and calm days clouds have been almost always seen round the summit. This has not been so in former years.

This is very probable. The steam that issues from the crater, in ascending and dispersing in the higher region, would produce clouds.

Nov. 8th.—The volume of steam has abnormally increased since yesterday. It is nearly the same as it was three weeks after the eruption. This morning the amount is still greater. Although its height is perhaps not greater than that observed

within ten days after the eruption, its volume does not seem to be less.

Oct 7th.—The new lake Akimoto rushed out cutting through the mud-field, after a heavy rain-storm. In the lower course of the river Nagase, the water level suddenly rose 9 ft. above the ground, causing great uneasiness among the people.

Oct. 20th, 6h. 32 min. 3 sec. a.m.—A slight shock was experienced.

Nov. 19th, 0h. 25 min. a.m.—A slight shock was felt; motion horizontal, direction N. S., duration 1 min. 30 sec. On this day snowfall was first observed on the summits of Ōbandai and Kushi-gamine.

Nov. 30th.—Thunder-claps were heard toward Bandai-san and Azuma-san, lasting about 20 minutes; have seen lightning twice.

Dec. 1st.—First snow-fall on the ground.

Dec. 5th.—Sound of distant thunder heard.

Dec. 30th.—Great storm swept the accumulating snow over Bandai, and with it the ashes on the mountain-flank. Peculiar rumbling noises heard in the mountain. People believing this to be a sign of a fresh outburst of Bandai were very much frightened.

Jan. 1st, (1889).—A slight shock was experienced at 7h. 10 min. p.m., lasting 2 seconds.

Jan. 23rd.—A *halo* observed, probably due to the refrigeration of the vapours of the steam from Bandai.

Feb. 8th.—Rumbling sound heard in Bandai, probably due to the falling of the crater-wall.

Feb. 17th.—Hibara-village was deserted on account of the encroachment of the new lake.

Feb. 18th, 5h. 30 min. a.m.—A slight shock.



In his last communication Mr. Kobayashi says that during the winter the action of rain, water, and snow, has greatly eroded and smoothed down the rugged points, the vertical walls and the precipitous hills in and round the crater, reducing them to much gentler inclines, and thus the grandeur and picturesqueness of the scenes have been considerably lost. This fact was confirmed by recent visitors to Bandai-san. From this it may be expected that such a bold scene as that shown in fig. 2, Pl. XXI, which is a sketch taken from the western edge of the crater just above Kaminoyu, about 20 days after the eruption, would not be long preserved.

### The Character of the Eruption.

The explosion of Bandai has furnished us with an example of a volcano, long dormant, bursting with terrific force. So far as we know the last great explosion took place more than ten centuries ago. Some minor eruptions are said to have occurred in subsequent years, but seem to have been of a local character. During the long period of rest, the original crater now known as Numano-taira, has in large measure lost its crater-like form by the disintegration of the surrounding walls. In such cases it often happens that subsequent eruptions take place at other parts of the mountain, breaking open new chasms along other lines of weakness. Such has indeed been the case with this last eruption of Bandai; the line of weakness lying to the north of the old crater so that the mass of the mountain was thrown toward the north into the Nagase Valley. There is now seen in the new crater a great fissure running N. 20° W. from the bottom of the horseshoe nearly to its mouth. Along this fissure runs a long row of steam jets, large and small, puffing and hissing and emitting immense volumes of white watery vapour. Pl. XXII

is a distant view of the mountain from a photograph taken by Prof. W. K. Burton, nearly a week after the eruption, showing the linear arrangement of the steam-fissures. It was along this line that the eruptive power of steam rent Ko-bandai into pieces.

It is manifest that the immediate cause of the eruption was the sudden expansion of steam pent up within the mountain. Of lava or pumice there is no trace. The grey coloured ashes which form a chief product of the explosion are evidently the powder of pre-existing rocks decomposed by the action of fumaroles, and have not been derived from fused magma.

The character of the explosion was thus comparatively simple, being to all appearance a sudden shattering of part of the mountain flank. The work of the explosion has been practically to tear off a portion of the side-wall of the old crater.

It has often been observed that the first action of some volcanic outbursts is characterized by extreme violence, large masses of super-incumbent materials which have accumulated in the crater being thrown out, or the side-wall being blown away, by the expansive force of steam. This first stage of the eruption is usually followed by minor ones accompanied either by lava flows or pumice ejections. Thus the finer particles or ashes ascending into the air are different in character in the successive outbursts; those which are ejected during the first stage of the eruption consisting largely of fragmentary materials, while those of the later eruptions are found to be more or less pumiceous, a fact showing that the latter are derived from the fused matter. The explosion of Bandai, characterized by its suddenness and violence, and effected in a very short time, may be likened to the first stage of eruption. But no subsequent discharge took place, nor were any signs of further disturbance discernible.

We have already indicated that the volcanoes in the vicinity of

Bandai, though classified as active, have never, within historic times, shown a true lava eruption. And this may be said to hold good for most of the active volcanoes on the Main Island. In fact, most of them, which had their climax of activity during Tertiary times, are now verging to extinction. This is due to the general and gradual abatement of volcanic force since the end of the Tertiary Era. Any great geologic changes which have taken place since then, have had to do with the general rise of the land surface above the sea-level. At present the Tertiary strata, some three or four hundred metres above the sea-level, cover a large part of the whole area of Japan. They consist principally of tufaceous deposits, are mostly of marine origin, and are often found surrounding or even underlying the volcanoes. These volcanoes would thus seem to have attained their maximum intensity at a time when proximity to the sea greatly favoured their activity. But the subsequent gradual rising of the land surface has had the effect of shifting the volcanoes further and further from the sea-board, thus greatly mitigating their action.

The eruptions which are usually experienced in these volcanoes in modern times seem to be essentially superficial. The recent catastrophe of Bandai may indeed be taken as a grand example of this kind of volcanic manifestation and may well be called an *explosive eruption*. The great horse-shoe-like chasm opened toward the north may be called an *explosion-crater*. Its appearance from the north side (fig. 1, Pl. XVI, and fig. 1, Pl. XXI) presents a striking resemblance to the deep chasms which are often characteristic of certain volcanoes, e.g., the 'Val del Bove' of Etna, the Caldera of Palma, &c., and at the same time suggests similarity of origin.

Perhaps it may be of interest here to refer to a volcanic outburst which occurred in Japan early last century and which seems to have strongly resembled the present Bandai eruption. It is the great lateral

eruption, which took place on the south-eastern flank of Fuji-yama in the 4th year of Hōyei (1707 A.D.). By this outburst a great chasm very similar in its character to that of Bandai, was opened on the mountain side. It is an explosion-crater not inferior in magnitude to the latter. Hōyei-zan is really a prominence on the outer rim of this great chasm. It has, however, hitherto been regarded as an example of a 'parasitic cone.' It is to be observed that, in case of the Fuji explosion, there were produced numerous volcanic bombs, which are now found scattered all around the crater, showing that there was ascent of lava. Another striking phenomenon is the presence of a magnificent series of numerous vertical dykes which traverse the side-wall of the crater. On the other hand there may be seen on the perpendicular walls of the newly opened crater of Bandai, bands of volcanic strata exposed, consisting of an alternation of old lava-streams, and of agglomerates of fragmentary materials, a singular feature of these strata being the absence of any noteworthy dykes passing through them. This fact would show that since the formation of the Bandai group, the mountain has been very little attacked by the intrusion of molten magma from the interior.

Again, as we have already seen, among the products of the late eruption there is no lava. There are, however, among the *debris*, especially near to the spot where the steam-jets are issuing within the crater, some greenish coloured rock-specimens with disseminated patches of iron-pyrites, and a white coloured sintery rock having a bleached appearance, almost wholly consisting of silica as shown by the analysis given in the sequel. These materials indicate the action of fumaroles and hot springs in altering the rocks in the interior of the volcano, and in depositing mineral matter while percolating through the crevices. Among the *debris* that ran down to the north, are often found porous or scoriaceous rocks of a reddish

or black colour, which some observers have referred to a molten origin. It is more than probable, however, that these rocks are the fragmentary materials which, having been ejected during the previous periods of activity in the history of the volcano, had accumulated in the form of volcanic strata, and taken their share in the building-up of the mountain. The destruction of Kobandai, which was itself a part of the side-wall of the volcano, reduced these strata to a powdery state, and scattered the scoriaceous materials imbedded in them abroad on the mud-field.

### **Survey of the Crater and the Volume and Weight of the Mountain destroyed.**

After great volcanic eruptions, surveys have sometimes been made with the view of estimating the dimensions of the parts blown away, or the amount of material ejected during the outbreak. The difficulties attending these attempts are obvious, for it happens very often that the seat of the outburst is inaccessible on account of lava flows or other dangerous obstacles that beset the way.

In estimating the dimensions of the newly opened explosion-crater which was formed by the destruction of Kobandai, and in deducing therefrom the volume and the weight of the mass that was thus removed, we encountered one serious difficulty, viz., ignorance of the original topography and former contour of the mountain. An unexpected advantage was however derived from the fact that, since in the case of Bandai the explosion lasted a very short time and no subsequent outbreaks took place, we could walk into nearly every nook and corner of the newly formed crater, and thus with comparative ease complete a survey which might otherwise have been almost impossible. The inaccessible or dangerous parts were the

fissure lines whence steam issued with great violence, the gorges filled with water (new lakes), and the regions at the base of vertical cliffs down which earth and rocks, and even slabs measuring one or two hundred metres, were constantly thundering. Otherwise the conditions were as favourable as could reasonably be expected in the circumstances. Not that the inside of the crater was anything like a level plain. Far from it; it was cut up by precipitous hills, deep chasms, wild depressions of all imaginable shapes and sizes. Pl. XIX shows a prominent rock-hill inside the crater, on which was located one of our stations. The crater-bed was full of these boulder-mounds, and was so irregular that we spent nearly two days in fixing upon a suitable base-line. We were, however, fortunate in finding a nearly straight narrow band in the bottom of a valley in which to locate the base-line.

For five successive days Mr. I. Toya laboured indefatigably, until all the important points were measured from prominent heights in and round the crater. When this was done, we removed to Ottate, a spa on the south flank of Ōbandai, and mapped the results of the triangulation.

The form of the crater, as deduced from the plan, is semi-elliptical, or like a horse-shoe. It opens toward the north, its bed gently inclining outwards. The plan in Pl. XXIII shows the general outline. It is surrounded by precipitous walls and steep cliffs of great height especially on the southern side, where a part of Kobandai still remains with rugged edges, and where Kushigamine exposes a clean section. The heights of the wall as may be seen from the numbers indicated on the plan gradually become smaller as we approach toward the mouth, at last reaching to the same level as the crater-bed. The heights in and round the crater were measured by taking altitude angles and were afterward referred to sea-level. The

position of the steam fissure running N. 20° W. is marked with star-like signs ; prominent hills, depressions, valleys, ponds, etc., are also indicated.

Roughly speaking the crater measures 2,463 metres or 8,080 feet across its mouth, which is the widest part from east to west. From the bottom of the horse-shoe to its mouth it is 2,274 metres or 7,460 ft. The total area of the crater-bed is 3.83 square kilometres or 946 acres, or nearly 1.5 square miles.

In the estimation of the volume and the weight of the mass blown away the chief difficulty encountered was our ignorance of the original contour. The original height of Kobandai, or Little Bandai, was assumed to be equal to that of Ōbandai, or Great Bandai, (1,840\* metres or 6,037 ft.). It was generally believed that Kobandai was a little lower than Ōbandai, probably owing to the fact that the former was situated further away from the more populous districts in the vicinity and was partly screened by the latter. We were told, however, by those who knew the district well that although Kobandai looked smaller in bulk than its sister peak, there was no appreciable difference in height, and that snow used to fall on the former earlier. This perhaps might be due to its more northern position. Lieut. Y. Nakashima of the Surveying Bureau of the Army, who subsequently surveyed Bandai-san, confirmed this view ; and after a thorough examination of the topography of the district and the forms of the various peaks, he concluded that Kobandai had been equal to, if not a little higher than, Ōbandai. On the sound judgment of this specialist we can safely place our confidence. We obtained permission to see the map he constructed. It was made with characteristic painstaking care, and every detail was ad-

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\*The barometric measurements by Messrs Y. Wada and N. Ōtsuka, of the Imperial Meteorological Observatory.

mirably carried out. We are glad to say that our measurements and those of Lieut. Nakashima agree well; some difference existed in regard to the heights of crater-walls, but this was more reasonable than otherwise, as they were daily being reduced in altitude by the falling in of the perpendicular edges and steep prominences.

The height of the crater-bed above the sea level was 1,170\* metres or 3,839 ft. The south-western part of Kobandai which was left undestroyed, exposed an almost perpendicular wall of 505 metres or 1,658 ft. overlooking the crater. From these and from the other data already mentioned, it was found that the part of the mountain that broke away had an altitude of 670 metres or 2,198 ft. above the crater, and that 164·6 metres or 540 ft. had been sheared off from its top. On Pl. XXIII is given a rough vertical section through the line AB, that is the section passing through the original summit and the highest fractured edge of Kobandai. The dotted line shows the parts blown off. It will be seen that the vertical line passing through the summit of the mountain was situated about 442 metres or 1,450 ft. N.E., from the fractured edge, its position being indicated on the plan by a cross. The main body of Kobandai and the north-eastern side were completely blown away, leaving a portion of the south western flank. The flank of Kushigamine sloping S.W. met that of Kobandai sloping N.E., practically forming one connected mass, and the consequence was that the latter's destruction was shared by the former in parts where they were so united. Kushigamine now stands overlooking the crater with a bared perpendicular wall 452 metres high.

It is also to be observed that the great fissure-line along which the mountain was rent nearly passed through the summit vertical,

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\* Also from Messrs. Wada and Ōtsuka's measurements.



or in other words, the fissure-line lay under the summit of Ko-bandai.

For ease of calculation the shape of the mountain was assumed to be conical, a near enough approximation. Then, subtracting the parts left undestroyed and making other allowances, we found the total volume of the mountain blown away to be 1.213 cubic kilometres or 1,587 millions cubic yards. This is equivalent to say that if the devastated area extending over 70 square kilometres or 27 square miles had been evenly covered with a stratum of earth, rocks and boulders, this stratum would have had an average thickness of 17.4 metres or 57 ft. The cubic content above given represents the gross total of the volume of the mountain destroyed, including not only the *débris* of earth and rock that descended the mountain-sides, but also the dust, ashes and boulders which were hurled into the air.

To calculate the weight of the material corresponding to this cubic content, we determined the specific gravity of different kinds of rocks and earth obtained from Bandai-san. The specific gravity of the pyroxene-andesite composing the mass of the mountain differed more or less with the different varieties met with, ranging from 2.58 to 2.71. On the average it may be taken as 2.65. But as the mountain consisted of much looser materials than these rocks such as pumice, scoriæ, &c., the density of the mountain would be much lower than this value. The mean specific gravity of the earthy materials thrown down by the eruption, as determined by Prof. J. Sakurai, was 2.172.

We may suppose without much error, that the mountain mass of Bandai consisted of rock and earthy materials in the proportion 1 : 2, and then we obtain from the foregoing numbers, as the density of

the mountain, 2.33.\* From this number and from the already estimated volume, the weight of the mountain destroyed was found to be 2,826,290 million kilogrammes or 2,782 million tons.

### Volcanic products of Bandai-san.

The volcanic rocks that compose the mass of Bandai-san, are comparatively of uniform character, and belong to that class of andesite which is of wide occurrence in Japan, viz., the Pyroxene-andesite which is now to be briefly described. This rock under its various modifications, may be seen piled up in layers in the side-wall of the newly opened crater, alternating with accumulations of loose products ejected from the volcanic vent in former times, such as pumice, scoria, fragments of obsidian, &c. Prof. B. Kotō considers that there are six of these principal layers. The rock-layers which doubtless consolidated from lava-flows, are divisible into two main types: the one being lighter coloured, and the other darker coloured, evidently more basic than the former. The first kind is well observed as a great band on the eastern side-wall down Kushiga-mine, more than 10 metres thick, overlaid by reddish coloured loose layers. Lower in position and separated by layers of agglomerate, is found the darker variety. The fragments that compose the agglomerate are also usually of the latter kind. These rocks have, however, essentially of identical mineral composition, and are probably to be considered

Volcanic rocks.

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\* Prof. J. Milne in calculating the weight of Japanese volcanoes has assumed the average density to be 2.5. (The Volcanoes of Japan—Trans: Seism. Soc. Japan Vol. IX, part II, 1886). Prof. T. C. Mendenhall, formerly of the University of Tokyo, in determining the force of gravity at the summit of Fujiyama, took the density of that mountain as 2.12, which was the mean of the densities of pulverized and porous rocks. (On pendulum experiments on the summit of Fujiyama for the purpose of ascertaining the force of gravity at that point—Trans: Seism. Soc. Vol. II, 1889). In the authors' Preliminary Report of the Bandai-san Eruption published in the Official Gazette of September 27th, 1888, the value of the density was taken a little higher, but it was since altered to the present figure.

the different facies of the same magma that supplied the materials for their formation.

The microscopical examination of these rocks shows that the ground-mass is microcrystalline, with a very little of colourless glass-basis in the lighter coloured variety between the microlithic plagioclase, while in the darker variety a brown coloured glass is found more abundantly. Numerous magnetite crystals and grains are in both cases always scattered within the general mass, and as enclosures.

The micro-porphyritic mineral components are Plagioclase, and Pyroxenes, which are represented by the monoclinic and the rhombic. The most frequent accessory component is Apatite. Among secondary minerals of less frequent occurrence may be mentioned Tridymite and Iron-pyrites.

The principal characteristics of the porphyritic components are here given :—

*Plagioclase*.—The porphyritic crystals are found generally in lathe-shaped outline, having characteristic twin-lamellæ of the albite-type. The extinction-angle of the plagioclase examined in the sections exhibiting these twin-lamellæ varies to a considerable extent; the range being from 20° to 30°. In general character the plagioclase is quite fresh and transparent, often with numerous glass-enclosures, which sometimes fill up the entire space of the crystal and are arranged in distinct zones. In polarized light, the phenomenon of zonal structure is often very typical; the extinction angles differing in the inner and the outer zones, thus showing a difference in the chemical composition of these layers.

The specific gravity of the plagioclase as determined by Thonlet's solution gave as a mean 2.686. These characteristics indicate that the chemical composition should approximate to that of Labradorite.

*Sandstone*.—Although this mineral under the microscope is so difficult of detection, we are justified in claiming its existence, since we observed cases in which the basal cleavage face of a glassy felspar devoid of twin-lamellæ, exhibited straight extinction.

The following chemical analysis of the 'feldspathic' components isolated from a

rock of Ōbandai, has been made in the laboratory of the Geological Survey Département. Somehow or other, the amount of foreign ingredients is so large that we cannot tell from it the true nature of its composition.

Si O <sub>2</sub> .....	61·26 %
Al <sub>2</sub> O <sub>3</sub> .....	19·55
Fe <sub>2</sub> O <sub>3</sub> .....	3·36
Fe O .....	4·06
Ca O .....	3·20
Mg O .....	2·54
Na <sub>2</sub> O.....	3·42
K <sub>2</sub> O .....	1·22
H <sub>2</sub> O .....	1·77

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100·38

*Augite*.—This mineral is found in well-defined forms or sometimes in grains. The common type of a twin with the face  $\alpha P \alpha$  as a twinning face, is frequently met with. It is usually greenish-yellow in colour, showing a feeble dichroism. It is usually fresh, with glass enclosures, and occasionally small needles of apatite.

*Hypersthene*.—The occurrence of the rhombic form of Pyroxene has received considerable attention in recent years. This mineral which has hitherto been regarded as rare, was found to be of wider occurrence than we had expected.\*

The rhombic pyroxene generally appears in more slender sections than the augite; breadth to length being as 1:3 to 1:5. Under polarized light the interference-colour is weak, and always shows a straight extinction. The pleochroism is very marked;  $\parallel \gamma =$  light green,  $\perp \gamma =$  greenish brown.

On examining the macropinacoidal section, under a convergent polarized ray, we can often very distinctly observe a biaxial interference-figure, which, however, on account of the thinness of the section appears elliptical. The dark cross which traverses the middle of the figure under crossed nicols, passes into an hyperbola as we rotate the section.

The rhombic pyroxene is often found in a cross shaped twin, the vertical axes of the two individuals making an angle of 60° with each other. This twin is there-

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\* An interesting Japanese occurrence of this mineral is in the Bonin Islands. See the preceding article in this Volume.—Y. K.

fore that which has often been met with in other localities, the twinning plane being  $P\infty$ . Parallel-intergrowth of the rhombic pyroxene with augite is also found. This has been dwelt on at length in the description of the Bonin specimens.\* Though in specimens from Bandai this is not so clearly defined, yet we have found some cases in which this phenomenon was very characteristically developed, the crystal of the rhombic pyroxene being surrounded on both sides, or flanked on one side, by an augite band.

The rhombic pyroxene isolated from the rock by means of Thoulet's solution and then lightly washed with hydrofluoric acid, was analyzed by Mr. T. Shimizu. It was impossible to separate the rhombic pyroxene from the augite. The following analysis is therefore that of a mixture.

Si O <sub>2</sub> .....	51.80 °
Al <sub>2</sub> O <sub>3</sub> .....	trace
Fe <sub>2</sub> O <sub>3</sub> .....	1.89
Fe O.....	18.86
Mn <sub>2</sub> O <sub>4</sub> .....	1.03
Ca O.....	7.96
Mg O .....	18.84
<hr/>	
	100.38

This leads to the composition nearly equivalent to  $2 \text{ Fe Si O}_3 + 3 \text{ Mg Si O}_3 + \text{Ca Si O}_3$ .

*Magnetite*.—It is very abundant in grains, and as enclosures, especially in the pyroxenes.

*Apatite*.—The crystals of this mineral sometimes occurs in a very characteristic form. It is dichroic;  $\parallel c =$  brownish, and  $\perp c =$  yellowish. The crystals usually with fine longitudinal striae, and with transversal cleavage-fissures. This kind of apatite is very abundant in the lighter coloured rock which was found in the bottom of the conical hole at Mine-yama.

*Tridymite*.—This mineral is seldom found in the fissures in microscopic form. In the rock imbedded within the hole at Mine-yama just referred to, it was found in well-defined crystals visible to the naked eye, nearly .5—1 mm. in size, lining the cavity of the rock in the manner of a druse. Some of them were found in

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\* l. c. p. 78.

characteristic twins. When taken out of the cavity and examined closely the crystals were found in hexagonal plates, in combination with the faces (when referred to the *hexagonal* axes)  $\text{oP}$ ,  $\infty\text{P}$ ,  $\text{P}$ ,  $\infty\text{P}_2$ , flattened along the base. Under crossed nicols, however, the plate was seen to consist of innumerable patches crossing at an angle of nearly  $120^\circ$ , and showing oblique directions of extinction. The specific gravity of the mineral determined by swimming it in the Thonlet's solution was 2.272.

For the chemical analyses, given below, of the Bandai rocks and ashes we are indebted to Prof. T. Wada, the Director of the Geological Survey. They are the result of a very careful analysis by Mr. T. Shimizu.

	I.	II.	III.
Si O <sub>2</sub> .....	59.66 <i>o/o</i> .....	59.56 <i>o/o</i> .....	59.47 <i>o/o</i>
Al <sub>2</sub> O <sub>3</sub> .....	15.51 .....	16.10 .....	17.12
Fe <sub>2</sub> O <sub>3</sub> .....	3.76 .....	6.28 .....	2.33
Fe O .....	5.10 .....	3.62 .....	5.69
Mn <sub>2</sub> O <sub>4</sub> .....	1.40 .....	1.80 .....	—
Ca O .....	6.56 .....	6.32 .....	7.24
Mg O .....	3.67 .....	3.68 .....	4.04
Na <sub>2</sub> O .....	2.50 .....	3.09 .....	2.23
K <sub>2</sub> O .....	1.08 .....	.80 .....	.30
S .....	.59 .....	— .....	—
P <sub>2</sub> O <sub>5</sub> .....	.18 .....	.18 .....	—
Loss by ignition—	.....	.44 .....	1.35
	100.31	100.67	99.77
Insoluble portion in HCl.		Insoluble portion in HCl.	
= 75.34 <i>o/o</i>		= 85.34 <i>o/o</i>	

- I. is a greenish-black rock taken from the rugged cliff of the partially destroyed wall of Yugeta-yama, containing a small quantity of iron-pyrites.
- II. is a reddish coloured rock, very frequently met with within the *débris*, especially in the conical mounds, somewhat powdery at the surface, due to the fumarolic action to which it was subjected within the volcano. There is more sesquioxide of iron in this rock than in the others. The sample for the analysis was obtained from the ejected masses near Tokoro-sawa, a ravine on the eastern side of Bandai.
- III. is the analysis of a rock from Bandai given by S. Nishiyama in his report to the Geological Survey, in 1887. The exact locality of this rock is not mentioned.

From these results it will be seen that the rocks of Bandai are nearly identical in their composition. We may, nevertheless, distinguish two types as we have already stated. One is a lighter coloured rock, the structure being usually porphyritic; the porphyritic components being pyroxenes and microfine plagioclase within a greyish coloured ground-mass. A typical example of the first type may be seen exposed on the side-wall of the new crater, as an extensive sheet in the great cliff forming now the western side of Kushigamine. A similar kind of rock was also found near the summit of Ōbandai. Microscopically examined the greyish white groundmass is micro-felspathic in character, with a small amount of colourless glass-basis. All the mineral components are quite fresh. The plagioclase of this rock was found to have a specific gravity of 2.682.

The other type of the pyroxene-andesite is a darker coloured rock evidently more basic than the first and resembling Basalt in its outer appearance; the glassy plagioclase being interspersed within the

dark, often compact, and resinous ground-mass, thus presenting a marked porphyritic structure.

Besides occurring in the form of a sheet of solid rock, it is also abundant among the fragments which compose the agglomerate, being, in this case, often scoriaceous in appearance. Under the microscope, the ground-mass is micro-crystalline, with a more or less brownish coloured glass-basis. In the scoriaceous rock just referred to, the hypersthene crystal is often highly pleochroic. The specific gravity of the plagioclase determined with Thoulet's solution is found to be little higher than that contained in the first type, being on an average 2.691.

To this type also belongs the rock which is exposed in a rugged cliff of the half destroyed Yugeta-yama, on the western edge of the new crater, and the analysis of which is given above (I). In this rock there is a very light brownish coloured glass-basis among the microlithic ground-mass. The black colour of the rock is, however, in this case, also due to another cause, viz., to the alteration which the crystals of pyroxenes have undergone. These crystals are seen to have altered into a peculiar dirty green coloured fibrous substance like viridite, the alteration proceeding from the fissures or from the periphery and often forming a pseudomorph. The altered product, diffusing itself into the surrounding ground-mass, imparts a peculiar dark greenish hue to the appearance of the rock. The alteration also often results in the formation of a reddish coloured iron-oxide. Sometimes the crevices of the rock are filled with iron-pyrites. It is highly probable that these phenomena have been greatly due to the action of fumaroles and hot-springs, the rock being found in close proximity to the Kaminoyu spa.

The following analysis of the white coloured rock, already referred to (p. 143), found near to the steam-fissures, together with that



of the water which has accumulated within the crater-basin from the condensing vapours, appears to show that corrosive gases have been active within the volcano, decomposing and altering the rocks. These acid gases have no doubt affected the rocks, by combining with bases to form soluble salts, which are now dissolved in the waters of the new lake within the crater, leaving as residue the white coloured sintery material, which consists almost wholly of silica.

Microscopically examined this white rock is seen to have been entirely altered in substance, but the original form of the porphyritic crystals is more or less preserved. A completely isotropic colourless substance is found filling up the spaces of all the crystal-sections, which nevertheless exhibit the characteristics of the original minerals. The decomposition of the andesitic rock by the action of acid gases had doubtless the effect of decomposing the mineral matters; the silica first separating out in a gelatinous form, and then consolidating to a porodine-amorphous state. Thus the isotropic substance mentioned above seems to be silica in the form of opal.

The fissures of these crystals are often filled with crystals of sulphur which may frequently be detected by the naked eye as well as under the microscope. Under crossed nicols it may be recognised by the fact that certain faint yellow coloured portions within the section exhibit vivid interference-colours, while the general ground is entirely dark. The crystals of plagioclase sometimes retain their original substance, which the pyroxene crystals never do. In the latter case it is interesting to observe that the alteration of the original substance into a fibrous viridite-like product had begun before it was completely decomposed into its present state, as we can still detect in it the characteristic trace of this alteration in the manner already described.

The analysis of this white rock found within the crater gave:—

SiO <sub>2</sub> .....	91·66 %
Al <sub>2</sub> O <sub>3</sub> .....	2·88
Fe <sub>2</sub> O <sub>3</sub> .....	1·20
CaO .....	·36
MgO .....	·10
S .....	·50
Loss by ignition	3·00
<hr/>	
	99·70

The following is the analysis of the water of the lake at the crater-basin, by Mr. M. Hida, 1,000,000 parts of water containing these substances:—

NaCl .....	154·07
Na <sub>2</sub> SO <sub>4</sub> .....	34·46
K <sub>2</sub> SO <sub>4</sub> .....	30·00
CaSO <sub>4</sub> .....	1136·57
MgSO <sub>4</sub> .....	286·09
MgCO <sub>3</sub> .....	178·58
SiO <sub>2</sub> .....	86·40
Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub> ...	trace
H <sub>2</sub> S ..	„
<hr/>	
	1906·17

Total evaporation-residue = 1947·40

The general description of the volcanic ash or dust that fell during the eruption has already been given (p. 111). It has a bluish-

grey colour, is usually very fine grained, but sometimes mixed with coarser rock-fragments. The microscopic examination of the dust shows that it is essentially made up of the same mineral components as the Pyroxene-andesite already described, proving that it was derived by the mechanical trituration of this rock. It consists of minute particles of the microfelsitic groundmass, mixed with crystal-fragments of Plagioclase, Sanidine, Augite, Hypersthene, Magnetite and Apatite needles with a very small amount of glass.

A specimen of the dust was brought from the town of Miharu, 38 kilometres to the east of Bandai-san. It is essentially the same as that which fell in the immediate neighbourhood of the volcano, only that it is somewhat finer grained. In mineralogical composition also, it is almost exactly similar, being chiefly made up of the finer particles of the rock, the crystal-fragments of plagioclase, the pyroxenes, and magnetite. These ashes, being comparatively heavy, do not seem to have fallen to any very great distance, thus differing from the fleecy pumiceous materials produced from molten lava at the time of other volcanic eruptions.

The following chemical analysis (I.) of the ash obtained by Mr. S. Ōtsuka of the Geological Survey, from Hikage in Biwa-sawa, when compared with those of the andesite rocks already given, will show how close is the agreement.

This ash, when treated with a mixture of hydrochloric acid, mixed with nitric acid in order to dissolve out the sulphur, gave a residue amounting to 52.92 %. This, when analyzed, gave the result as in column II.

	I.	II.	III.
		Insoluble portion.	Soluble portion. (by difference.)
SiO <sub>2</sub> .....	59·70 %	40·11	19·59
Al <sub>2</sub> O <sub>3</sub> .....	16·68	6·75	9·93
Fe <sub>2</sub> O <sub>3</sub> .....	5·43	1·44	3·99
FeO .....	2·05	—	2·05
Mn <sub>3</sub> O <sub>4</sub> .....	·98	trace	·98
CaO .....	5·20	1·75	3·45
MgO .....	2·35	1·08	1·27
Na <sub>2</sub> O .....	2·67	1·25	1·42
K <sub>2</sub> O .....	·99	·71	·28
S .....	2·25	—	2·25
SO <sub>3</sub> .....	·95	—	·95
P <sub>2</sub> O <sub>5</sub> .....	·15	—	·15
Loss by ignition ....	·90	—	·90
	<hr/>	<hr/>	<hr/>
	100·30	53·09	

The ash contained some soluble matters which on being extracted with cold water gave traces of lime, chloride, and sulphate.

The analysis of another, and a somewhat more stony sample of the ash was made by Mr. H. Yoshida of the Imperial University, with the following result :—

Si O <sub>2</sub> .....	61·82 %
Fe <sub>2</sub> O <sub>3</sub> + Al <sub>2</sub> O <sub>3</sub> .....	28·10
CaO .....	5·73
MgO .....	·79
K <sub>2</sub> O .....	1·10
Na <sub>2</sub> O .....	2·42
	<hr/>
	99·96

## Reports.

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Under this heading, we arrange in tabular form the answers to inquiries made to school-masters and others living in the provinces near Bandai-san. We have already referred to the particulars obtained in this way, and the great help we derived in the preparation of our paper from the answers so received.

In the Table when the phenomena under consideration were reported not to have been observed, the space is marked with a dash; when it was not known whether certain phenomena occurred or not the corresponding space is left blank.

Unless otherwise stated, the date refers to the 15th of July, 1888—the day of the eruption.

1 *Shaku* is nearly equivalent to 0·303 metres or one foot.

1 *Sun* =  $\frac{1}{16}$  of 1 *Shaku*.

1 *Bu* =  $\frac{1}{100}$  of 1 *Shaku*.

1 *Ri* = 3·93 kilometres or 2·44 miles.

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# *REPORTS.*

NAME & ADDRESS OF OBSERVERS.	DIRECTION AND DISTANCE FROM BANDAI-SAN.	SOUND.	ASHES.
No. 1. T. Uda, Kokai village, Yama-kōri, Prov. Iwashiro.	E. S. E. 5 kilometres. 3.2 miles.	A black column of smoke ascended high into the air; the sound of the explosion was something terrific, lasting for about 30 minutes.	Ashes fell in abundance in the neighbourhood of the mountain for about an hour and it was not until about 4 o'clock p.m. that it entirely ceased. I was bathed by ashes. The thickness was 1 <i>shaku</i> near Shirakijō, and 6 <i>sun</i> near Hi- nokuchi. The ashes were pow- dery, but occasionally mixed with rocky fragments which struck upon our bodies.
No. 2. U. Hayakawa, Sasakawa village, Yama-kōri, Prov. Iwashiro.	W. 20 kilometres. 18 miles.	A rambling sound was heard by some.	
No. 3. S. Yamamoto Kitagata, Yama-kōri, Prov. Iwashiro.	W. N. W. 15.7 kilometres. 9.8 miles.	Sound like distant thunder.	No ashes fell.

EARTHQUAKES.	METEOROLOGICAL CONDITIONS.	MISCELLANEOUS NOTES.
<p>No earthquakes on previous days. A few minutes before the eruption curious rumblings were heard, and while we were wondering what was the matter, a violent shaking of the earth occurred about 3 times. At the end of the 3rd shock, a black column of smoke ascended from Bandai-san. The character of this earthquake was different from that usually experienced, heavy up and down movements predominating.</p>	<p>Very fine. No cloud streaked the heaven. It was however somewhat hotter than usual. No wind before the eruption. Soon after the eruption, a great whirling wind suddenly swept over the eastern part of the mountain with great violence, destroying Shibutani, Shirokijō, Ojigakura, etc.</p>	<p>Some people say that they have seen fire on the mountain; I saw two flashes of lightning from the rising steam. At Oda village more than 2 <i>ri</i> away on the eastern side of the mountain, a spring became as warm as hot bathing water while the ashes were still falling; but at about 4 o'clock p.m. it became cold again. This is evidently due to the effect of heat imparted by falling ashes, which often scalded the naked parts of the body. The ashes also had the smell of sulphurous acid. Thunder claps were heard, followed by heavy rain continuing 3 or 4 minutes, which was also warm having the temperature of at least 70-80° Fah.</p>
<p>No earthquake on previous days. On the 15th a slight shock of very short duration was felt. It passed unheeded by most people.</p>	<p>Very fine. Thermometer 88° F.; atmosphere calm. At the time of the eruption a gentle breeze blew from the west.</p>	<p>Two travellers who were at the time of the outburst, resting at a pass of a neighbouring ridge, observed a black cloud rising from behind Bandai, among which were occasionally seen reddish coloured objects. The phenomena lasted for a few minutes; after this a white column of steam was seen ascending from these places; at the same time Kobandai entirely vanished from view.</p>
<p>A slight shock at 4 p.m. on the 12th.</p>	<p>Very fine; calm in the morning; it was little hotter in the afternoon, when the thermometer stood at 88 F., and the northern wind began to blow.</p>	<p>Black columns of smoke were seen rising to a great height; neither lightning nor fire were seen. There was observed also a light reddish coloured cloud spreading at right angles to the columns of the smoke.</p>



NAME & ADDRESS OF OBSERVERS.	DIRECTION AND DISTANCE FROM BANDAI-SAN.	SOUND.	ASHES.
No. 4. T. Kamizuma, Tajima, Aizu-kōri, Prov. Iwashiro.	S. W. S. 47.3 kilometres. 29.3 miles.	Rumbling sound heard twice. It was, however, so slight that it was unnoticed by many.	———
No. 5. H. Kotō, Kawaguchi, Ōnuma-kōri, Prov. Iwashiro.	W. S. W. 47.1 kilometres. 29.3 miles.	At 8 h. 40 min., and 9 h. 15 min. a.m., sound was heard.	No ashes.
No. 6. N. Yamasaki and T. Mafune, Fukuyoshi, Asaka-kōri, Prov. Iwashiro.	S. 21.6 kilometres. 13.4 miles.	The detonation of the explosion was very intense, continuing for nearly 5 minutes. It was also heard for several hours afterwards. People regarded the rumbling as a premonitory sign of the earthquake.	No ashes.
No. 7. S. Sugeno, Harimichi, Adachi-kōri, Prov. Iwashiro.	E. 45.2 kilometres. 28 miles.	People inside the houses did not notice the sound. Peasants who were working in the field heard it. It continued for nearly 5 minutes. The screech of the pheasant which is generally heard during an earthquake, was also noticed.	No ashes.
No. 8. T. Katō, Naganuma, Iwase-kōri, Prov. Iwashiro.	S. E. S. 35.3 kilometres. 22 miles.	Low rumblings noticed.	———

EARTHQUAKES.	METEOROLOGICAL CONDITIONS.	MISCELLANEOUS NOTES.
<p>About 5 days before the eruption somewhat strong earthquakes occurred twice. A slight shock at about 7 a.m. on the day of the explosion.</p>		
<p>At about 0 h. 30 m. a.m. on the 11th of this month, an earthquake was felt.</p>	<p>Very fine ; some patches of cloud seen in the eastern sky. Western breeze at the time of the eruption.</p>	<p>No lightning or smoke seen ; no change in rivers, springs, wells, etc.</p>
<p>No earthquake on previous days. At about 8 a.m. a very severe shaking experienced continuing for 5 minutes. It was very violent and the people felt as if the ground was suddenly upheaved.</p>	<p>Very fine before the eruption ; the wind was northerly ; after the eruption it appeared as if it had changed to N.W.</p>	<p>From the ascending columns lightning was emitted. The smoke soon covered the top of Bandai. N.W. wind blowing at the time ; ashes fell at the village of Yokohama, nearly 2 <i>ri</i> N.E. from this place, coating the vegetation with greyish powder.</p>
<p>Nobody felt any shock.</p>	<p>Very fine, and no cloud, calm, temperature reaching to 90° F. in sunshine. N.W. wind at the time of the outburst.</p>	<p>While the heaven was clear, a very peculiar cloud (which I afterwards learned to have been steam) appeared near Adatara-san. There was neither lightning nor fire.</p>
<p>At 7 a.m. a slight shock, before we heard the rumbling noises.</p>	<p>Very fine ; calm. Weather somewhat changed in the afternoon.</p>	<p>A black streak of cloud appeared, with beautiful stripes of purple, red, yellow, and green, probably caused by the reflection and refraction of sunlight falling upon steam.</p>

NAME & ADDRESS OF OBSERVERS.	DIRECTION AND DISTANCE FROM BANDAI-SAN.	SOUND.	ASHES.
<p>No. 9.</p> <p>—</p> <p>Motomiya, Adachi-kōri, Prov. Iwashi-ro.</p>	<p>E. S. E. 29.5 kilometres. 18.8 miles.</p>	<p>At about 7 h 30 minutes a.m., a roaring sound.</p>	<p>On the north-western mount- ains, a peculiar cloud of sharply defined form appear- ed, which gradually spread out in a circular form, like an um- brella, at the same time becom- ing lighter in colour. As the cloud spread wider, grey col- oured ashes of the size of mil- let grains began to fall at about 8 a.m. This was fol- lowed by the fall of powdery ashes; all the vegetation wore a grey colour.</p>
<p>No. 10.</p> <p>—</p> <p>Wakamatsu, Aizu-kōri, Prov. Iwashi-ro.</p>	<p>S. W. 15.7 kilometres. 9.8 miles.</p>	<p>Thundering noises were heard accompanied by the as- cent of black smoke.</p>	<p>No ashes.</p>
<p>No. 11.</p> <p>—</p> <p>Fukushima, Shinobu-kōri, Prov. Iwashi-ro.</p>	<p>E. N. E. 37.3 kilometres. 23.2 miles.</p>	<p>Distant sound was heard.</p>	<p>—</p>
<p>No. 12.</p> <p>K. Mita, Onoshinnachi, Tamura-kōri, Prov. Iwaki.</p>	<p>E. S. E. 74.8 kilometres. 46.2 miles.</p>	<p>At about 8 a.m., the sound was heard thrice at short in- tervals by those who were outside of houses.</p>	<p>The fall of ashes began at about 9 a.m. and continued till about 12.</p>

EARTHQUAKES.	METEOROLOGICAL CONDITIONS.	MISCELLANEOUS NOTES.
Strong shock was felt.		Ascent of smoke observed. The umbrella-shaped cloud disappeared at about 10 a.m.
There was a smart shock shortly before the eruption, then it was followed by violent heavings of the ground. The houses were observed to sway.	Fine weather, very gentle breeze.	Smoke ascended very high.
A moderate earthquake.		
A shock of short duration on the day before the eruption.	Very fine; 82° F. at noon; somewhat cool at 7-8 a.m.	On account of ashes the atmosphere became very dim and heavy; in the direction of Bandai a thick cloud appeared.

NAME & ADDRESS OF OBSERVERS.	DIRECTION AND DISTANCE FROM BANDAI-SAN.	SOUND.	ASHES.
No. 13. M. Murata, Miharu, Tamura- kōri, Prov. Iwaki.	E. S. E. 38 kilometres. 24 miles.	Tolerably loud sound was heard.	Ashes began to fall from about 9 h. 30 min. a.m., and continued until 2 h. 30 min. p.m. During this interval the atmosphere had a misty ap- pearance; the film of the ashes turned vegetable and other objects into greyish hue. Ashes fell at one time so thickly as to fill the eyes and nostrils of the passers-by. The street was almost impassable. [A sample of the ash was sent].
No. 14. Taira, Iwamai- kōri, Prov. Iwaki.	S. E. 86.4 kilometres. 53.7 miles.	Peculiar sounds were heard by some continuing for about 2 minutes.	At about 10 a.m. finely powdered ashes fell, coating the vegetation and roofs.
No. 15. N. Ōishi, Kohama village, Naraha- kōri, Prov. Iwaki.	E. S. E. 86.4 kilometres. 53.7 miles.	Noises heard for about 3 minutes.	A greenish white coloured powder or ash fell forming a thin coating over mulberry leaves, &c. In the village of Kawanchi, 5 ri west of this place, the ashes fell in the form of lumps about the size of a pea.
No. 16. F. Kurosawa, Shimo-Ishii village, Shirakawa-kōri, Prov. Iwaki.	S. S. E. 78.5 kilometres. 48.8 miles.		

EARTHQUAKES.	METEOROLOGICAL CONDITIONS.	MISCELLANEOUS NOTES.
<p>Earthquake occurred before the eruption, continuing for about 20 seconds. It felt as if something had fallen in the next room. In general character it differed from the shocks usually felt.</p>	<p>Very fine; gentle N.W. breeze, 85° F.; it was a little stronger after the eruption.</p>	<p>A dark coloured cloud seen in the N.W., gradually spreading as it ascended. At about 10 h. 10 min. a.m. that part of the heavens became so thickly covered with misty cloud that we could not see the mountain for 20 min.</p>
<p>Feeble shocks at about 8 a.m. on the 14th, and at about 4 p.m. on the 15th.</p>	<p>Very thick mist in the morning, but gradually began to clear away from about 8 a.m. It was quite fine at noon. Thermometer 75° F., at 6 a.m., 90° F. at 12 a.m. About 8 a.m. W. wind prevailed but afterwards turned to S. At 11 a.m. it became S.E.</p>	<p>The thick smoke rising from Bandai-san, which was generally regarded as cloud, looked black and somewhat reddish. During sun-set sparkling rays of red light were emitted from the cloud.</p>
<hr/>	<p>Very fine and calm early in the morning. At about 9 a.m. a black cloud appeared on the west, and became dark, but it cleared again in the evening. Therm. 85° F.</p>	<p>In the direction of Bandai, cloud of an elliptical form was seen.</p>
	<p>Very fine; temp. 95° F. at noon; a gentle north wind.</p>	

NAME & ADDRESS OF OBSERVERS.	DIRECTION AND DISTANCE FROM BANDAI-SAN.	SOUND.	ASHES.
No. 17.  Watari, Watari- kōri, Prov. Iwaki.	N. E. 80.5 kilometres. 50 miles.		
No. 18. S. Chika & R. Ashi- kawa, Yonesawa, Okitama-kōri, Prov. Uzen.	N. 33.4 kilometres. 20.7 miles.	At about 8 a.m. thundering noises were heard in the south- ern mountains.	No ashes.
No. 19. T. Kusaka, Shikase village, Higashi- Kanbara-kōri, Prov. Echigo.	W. 53 kilometres. 33.2 miles.		
No. 20.  Takai-kōri, Prov. Shinano.	W. S. W. 164 kilometres. 102 miles.	It was reported that a pe- culiar detonating sound was heard on the morning of July 15th; it was attributed to the roaring sound sometimes au- dible from Asama-yama.	
No. 21. K. Nakashima, Kinboku-san, Island Sado.	W. N. W. 161 kilometres. 100 miles.	While I, in company with others, was ascending Kinbo- ku-san in the island of Sado on the morning of July 15th, we heard curious dull rum- blings which we thought to be the firing of heavy guns in the neighbouring harbour.	

EARTHQUAKES.	METEOROLOGICAL CONDITIONS.	MISCELLANEOUS NOTES.
<p>At 11 h. 50 min. a.m. a slight earthquake lasting for only about 10 seconds was felt; motion horizontal.</p>	<p>Cloudy, a warm wind, 78° F. at noon.</p>	
<p>A feeble shock at 3 p.m. on the 14th; at 7 h. 30 min. a.m. and at 8 h. 20 min. a.m., on the 15th feeble earthquakes; the former was a little stronger than the latter.</p>	<p>Extremely fine. 90° F. at noon. W. wind.</p>	<p>While the weather was extremely fine, we observed the rise of a peculiarly grey coloured cloud-like smoke in the southern sky over Azuma-san.</p>
<p>At about 4 p.m. on the 14th a smart shock was felt and was soon followed by strong shakings of the ground which lasted less than 3 min.</p>	<p>Very fine; 85° F. at noon; gentle E. breeze.</p>	<p>After the eruption, the water of Akagawa diminished and became turbid.</p>



Letters of inquiry were sent to the following places, but we received answers to the effect that nothing which could certainly be referred to the influence of the volcanic eruption was noticed in these districts.

Localities.	Direction from Bandai-san.	Distance from Bandai-san.
Sanjō, Prov. Echigo. ....	W.	{ 96·2 kilm. 59·8 miles.
Mizuhara, Prov. Echigo. ....	W.N.W.	{ 76·6 kilm. 47·6 miles.
Muramatsu, Prov. Echigo. ....	W.	{ 76·6 kilm. 47·3 miles.
Nagaoka, Prov. Echigo. ....	W.	{ 106·0 kilm. 65·9 miles.
Mito, Prov. Hidachi. ....	S.S.E.	{ 135·5 kilm. 84·2 miles.
Takahagi, Prov. Hidachi. ....	S.S.E.	{ 106·0 kilm. 65·9 miles.
Noki, Prov. Shimotsuke. ....	S.	{ 153·2 kilm. 95·2 miles.
Nikkō, Prov. Shimotsuke. ....	S.S.W.	{ 106·0 kilm. 65·9 miles.
Karasuyama, Prov. Shimotsuke. ....	S.	{ 104·1 kilm. 64·7 miles.
Tochigi, Prov. Shimotsuke. ....	S.S.W.	{ 133·5 kilm. 83·0 miles.
Shiobara, Prov. Shimotsuke. ....	S.	{ 70·7 kilm. 43·9 miles.
Namiye, Prov. Iwaki. ....	E.	{ 82·5 kilm. 51·2 miles.
Haranomachi, Prov. Iwaki. ....	E.	{ 78·5 kilm. 48·8 miles.
Ishikawa, Prov. Iwaki. ....	S.E.	{ 62·8 kilm. 39·0 miles.
Yamagata, Prov. Uzen. ....	E.N.E.	{ 79 kilm. 49 miles.
Iwahashi, Prov. Uzen. ....	N.W.	{ 86·4 kilm. 53·6 miles.
Sendai, Prov. Rikuzen. ....	N.E.	{ 103 kilm. 63·4 miles.

PLATE XV.

## Plate XV.

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Map of Bandai-san district. The area devastated by the *débris* of rock and earth caused by the destruction of Kobandai is distinguished by the grey colour. The position and form of the crater are indicated.



Large and small conical mounds standing out from the surface of the *débris* in immense number.



Principal steam-fissures in the crater.



Hot springs.



Marks the direction of the hurricane-blast and the area swept by it.

Heights are given in metres.

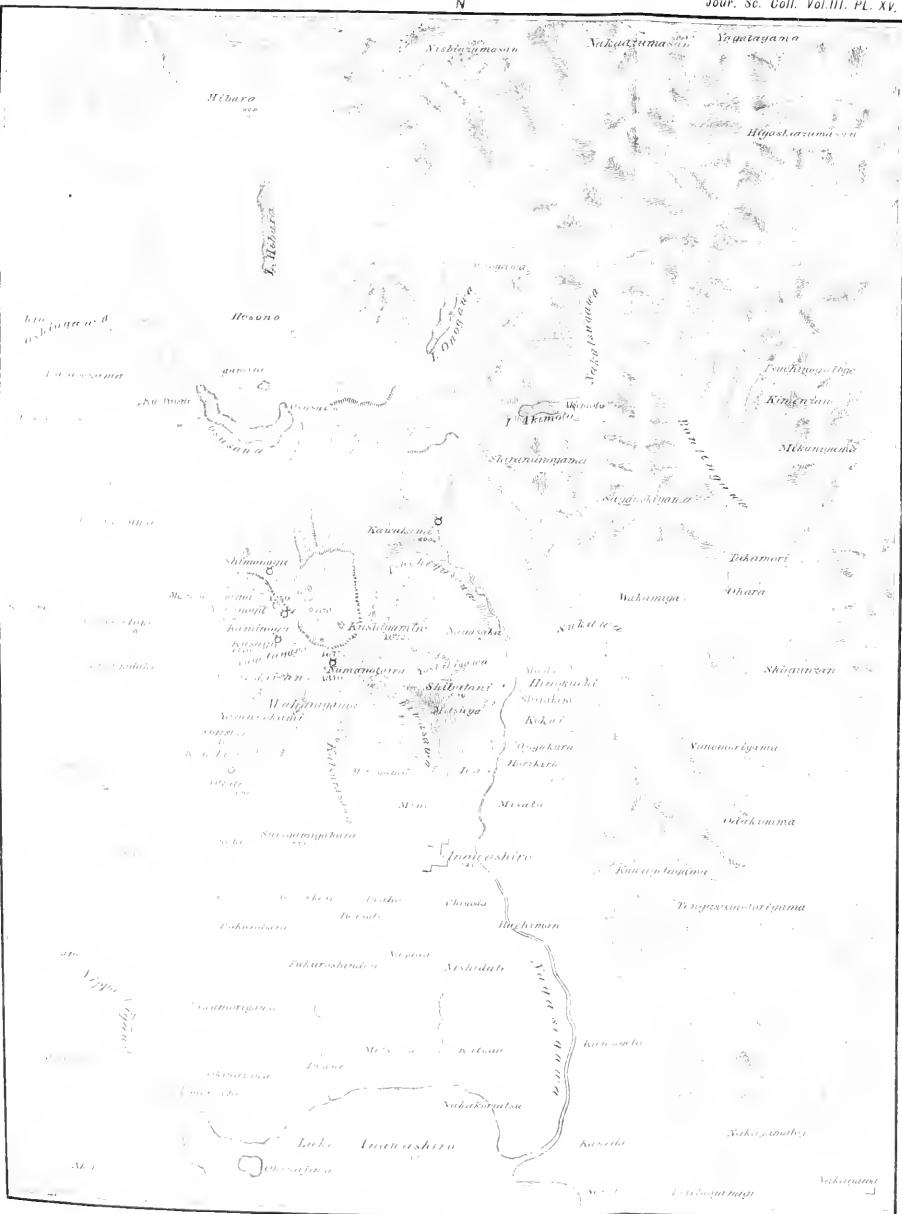




PLATE XVI.

## Plate XVI

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*Fig. 1.*—Distant view of Bandai-san, from N. W. side as seen from the hill ridge of Nagamine.

- |                          |  |
|--------------------------|--|
| <i>a.</i> Ōbandai.       | <i>b.</i> (The rugged and the highest part of the crater-wall. |
| <i>c.</i> Kushigamine.   | <i>d.</i> Marumori-yama.                                       |
| <i>g.</i> Kawageta-yama. | <i>h.</i> Mud-field.   |

The forest in the foreground being situated on a ridge, escaped destruction by the *debris*.

*Fig. 2.*—View of Numano-taira near the edge of the new crater; the perpendicular cliff of Ōbandai facing this spot. Large hollow depressions (*k*) are found partly filled with water (p. 124.) The ground is covered with grey coloured ashes and smaller rock fragments. For other letters refer to *Fig. 1*.

[From sketches by Y. Kikuchi.]

Fig. 1.

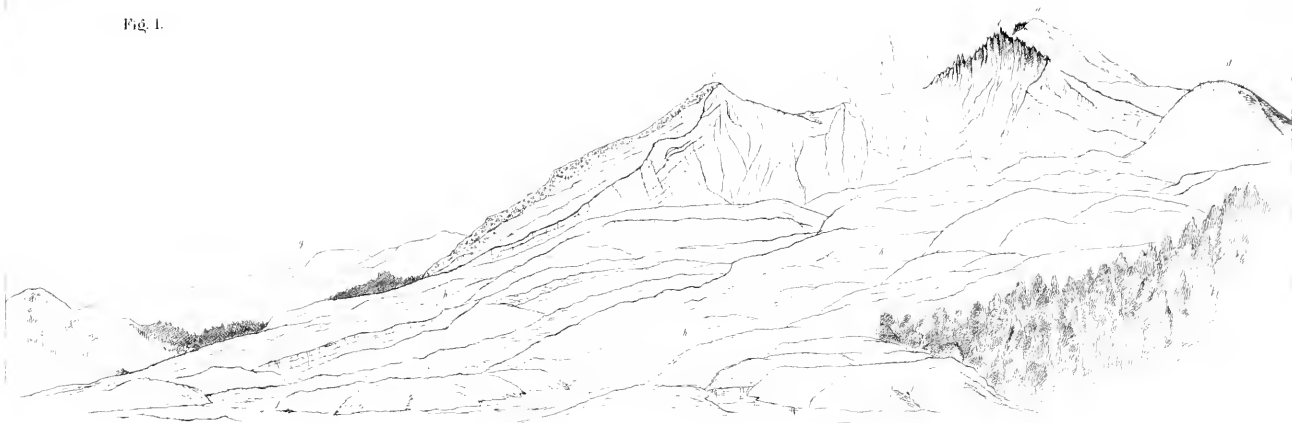


Fig. 2.

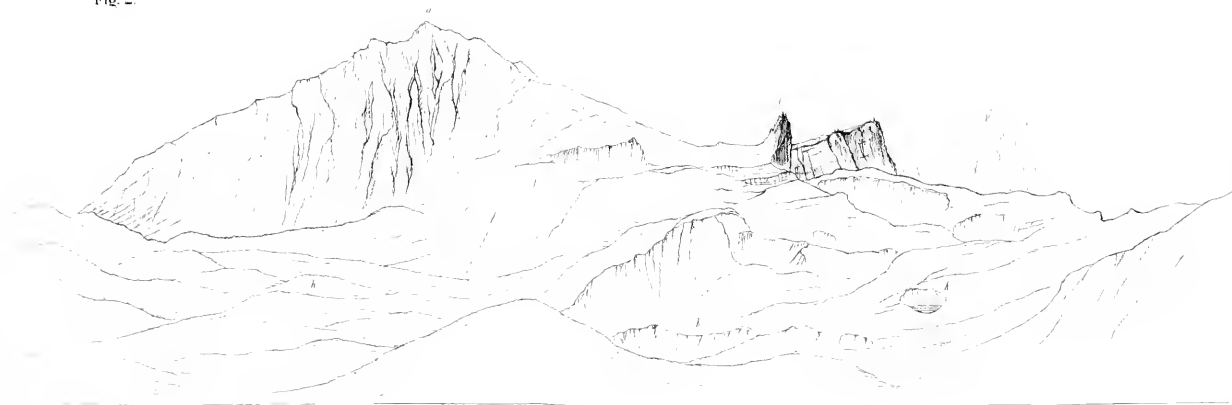






PLATE XVII.

## Plate XVII.

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*Fig. 1.*—Distant view of Bandai-san as seen from the outskirts of Inawashiro, with the village of Miné in front.

- a.* Ōbandai.
- b.* Kushigamine.
- c.* Akahani-yama.
- d.* The smaller mud-stream, which ran down through the Biwa-sawa (the ravine between *b* and *c*), descending upon, and burying a part of the village of Miné (p. 107–108).

[*From photograph.*]

*Fig. 2.*—Sketch taken from Biwa-sawa.

- a.* Ōbandai with rugged and precipitous wall on the northern side.
- b.* Kushigamine.
- c.* Akahani-yama.
- d.* Upper course of the mud-stream toward Miné.
- f.* Futatsu-iwa (p. 98).

[*From sketch by Mr. H. Hirauchi.*]

Fig. 1.



Fig. 2.





PLATE XVIII.

## Plate XVIII.

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*Fig. 1.*—Extensive and nearer view of mud-field of Miné.

*Fig. 2.*—Example of large boulders carried down along with the mud-current and forming conical mound near Kawakami. Mounds of this kind were formed on the *debris* in great members (p. 110–111).

[From photographs.]

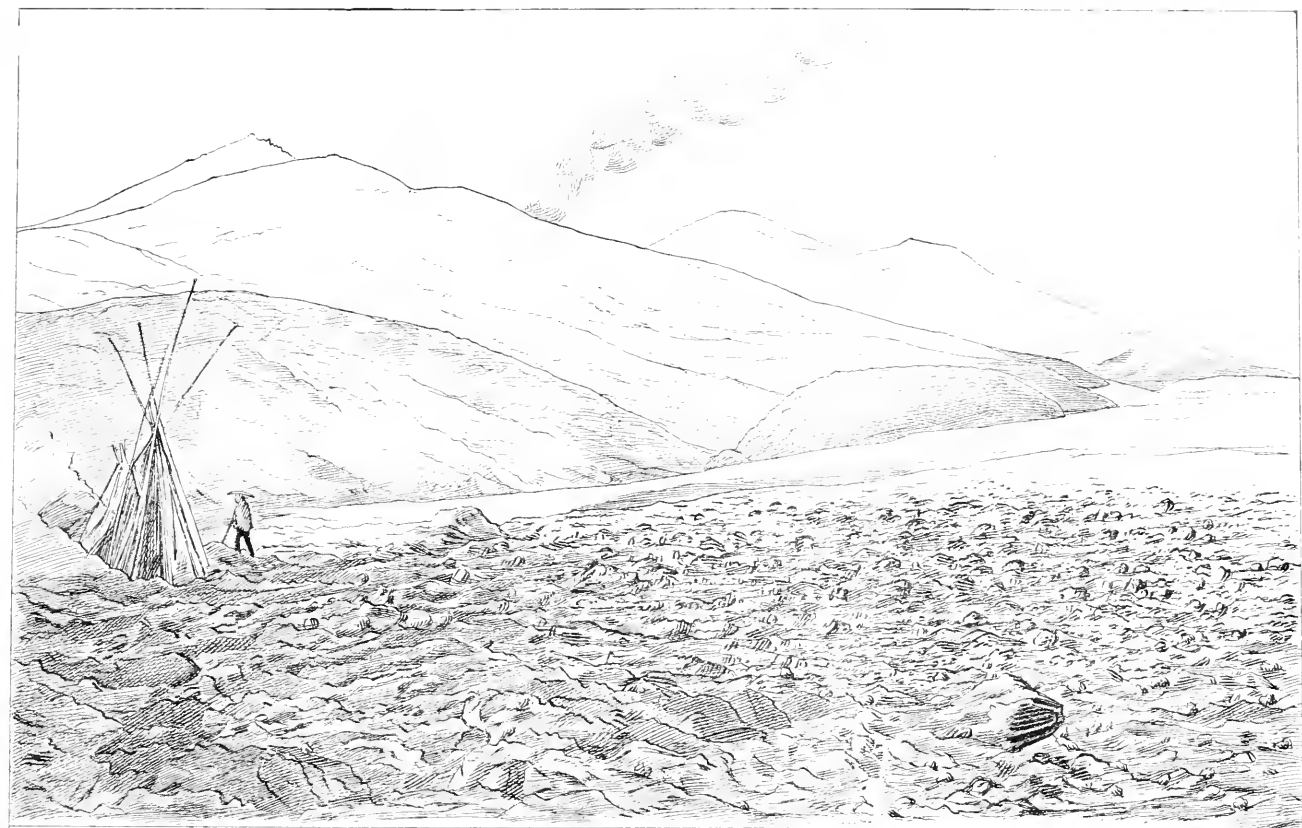






PLATE XIX.

## **Plate XIX.**

A rock mound prominently standing out in the inside of the crater, that formed one of the stations of the survey.

Encircling crater wall on the background; Kushigamine on the left with its fractured side exposing volcanic strata; on the right a part of the rugged cliff seen through the stream.

The gigantic block on the right foreground is one of the many boulders scattered about in the crater.



From photograph taken by Prof. W. E. Burton



PLATE XX.

## Plate XX.

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Mud stream in Nagase Valley below Kawakami facing S. E.  
The *debris* of rock and earth descending in a swift torrent left wave-like traces on the side of the hill (p. 108), and filled up the valley perhaps not less than 40 metres deep.



*From Photograph by Prof. W. K. Burton.*





PLATE XXI.

## Plate XXI.

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*Fig. 1.*—Crater as seen from the north near the village of Hibara, three weeks after the eruption, and at a distance of 9 kilometres—the position from which the grand view of the devastation could be seen with full effect. Among the *débris* from the crater downward, may be seen innumerable numbers of conical mounds. On the right hand are seen the hillsides bared by the torrent of mud. The main feature of this figure is analogous to *Fig. 1*, *Pl. XVI*. For the names of the principal peaks refer to that plate.

*Fig. 2.*—View of the crater twenty days after the eruption, from its edge just over the solfatara of Kaminoyu, looking down the crater, at the bottom of which a small lake or pond may be seen. On the right hand side is the characteristically rugged cliff of Yugeta-yama, on the proximity of which are numerous withered trees stripped of leaves. In the middle of the figure are numerous fissures puffing off steam and behind stands Kushigamine. The distant mountain in the back-ground is the old volcano of Dake-yama.

*Fig. 3.*—Distant view of Bandai-san from its south side as seen from the town of Wakamatsu, four weeks after the eruption. The most prominent pointed peak is Ōbandai, exposing on its flank a bare valley called Kara-sawa. The dotted line on the left shows the original form of Kobandai previous to the eruption. The prominence immediately below is the remains of Yugeta-yama. Down below is seen Marumori-yama as a small protuberance. The peak to the right is Kushigamine. The hills ridges in the foreground are the part of the Aizu-plateau.

[From sketches by Y. Kikuchi.]

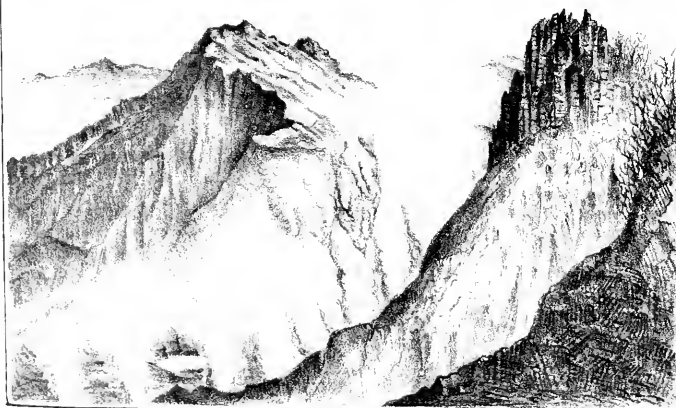




PLATE XXII.

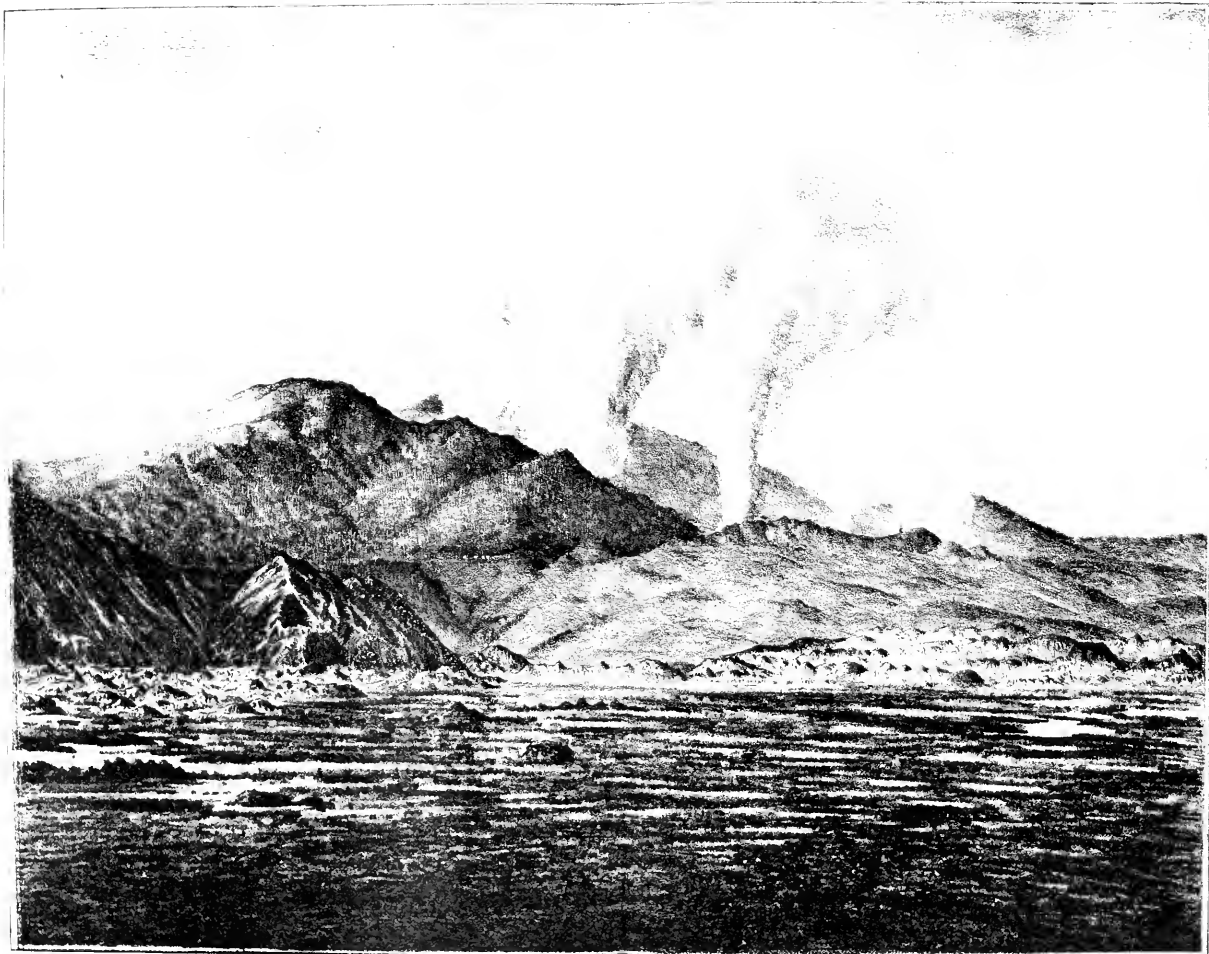
## Plate XXII.

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View of Bandai-san from its north-eastern side at distance of about six kilometres, from the former site of the hamlet of Akimoto. The linear arrangement of steam-fissures is at once apparent to the eye. The level tract in the foreground shows the levelling effect by the mud stream, in which may be seen accumulations of water. A little farther away we find innumerable conical mounds. Just above the masses of these mounds on the left hand side, is seen the rocky exposure of a ridge which has had its loamy crust completely scraped off. Between this ridge and the prominent tree-covered peak of Kushigamine just behind, stretches the valley of the Nagase-gawa.

On the right hand side behind the group of conical mounds is seen the extensive slope, formerly known as Ōbudaira, converted into waste desert. The prominence at the termination of the steam column is Marumori-yama.

*[From photograph taken by Prof. W. K. Burton  
one week after the eruption.]*



PHOTOGRAPH BY LEO. A. BULLARD





PLATE XXIII.

## Plate XXIII.

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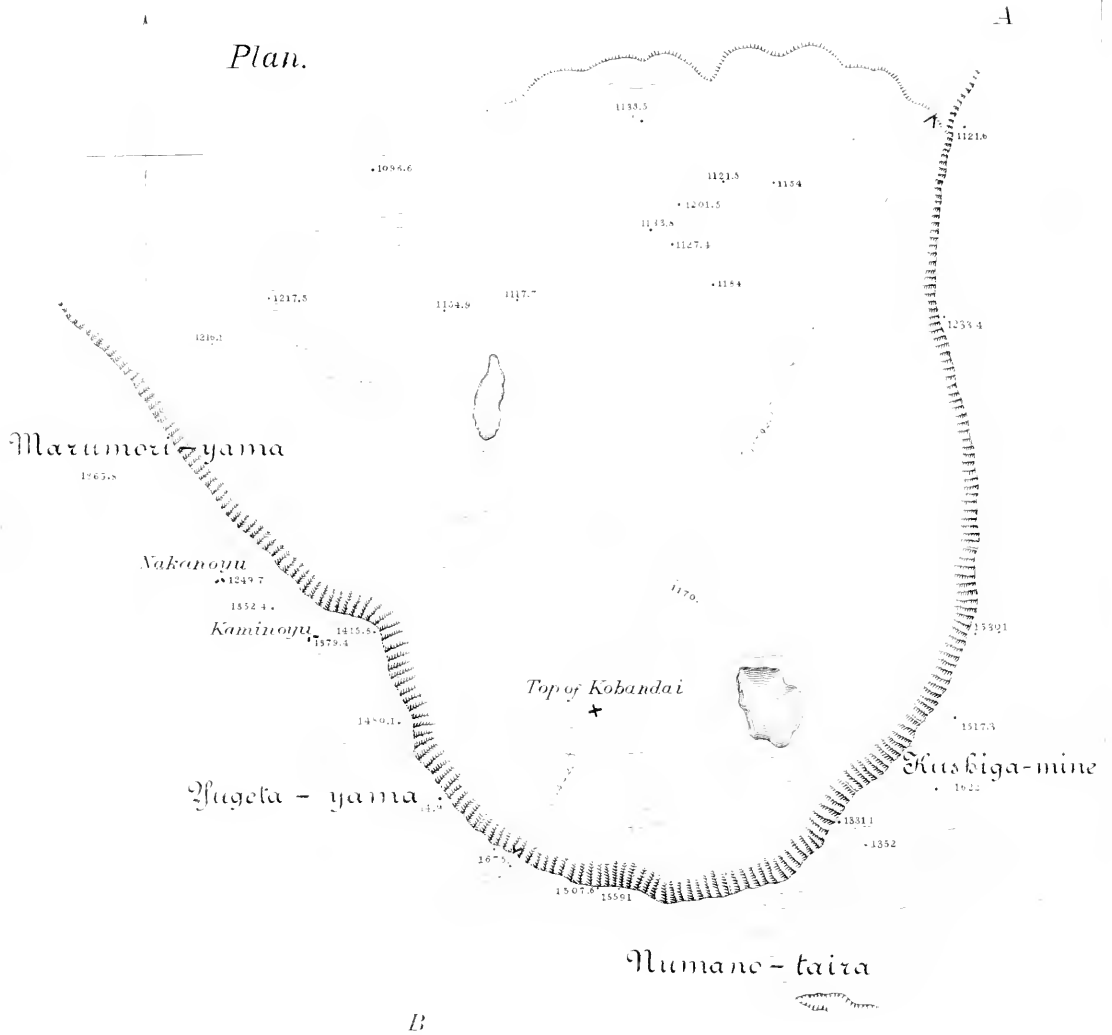
*Plan.*—Form of the crater as deduced from the triangulation survey. The contour lines in the crater indicate roughly the principal elevations and depressions.

- ✕ The original top of Kobandai which is in the line of the steam fissure.
- \* Principal steam fissures.

*Section.*—The profile of the crater through the line *AB*, or the line passing through the original top of Kobandai and the highest part of the crater-wall. The dotted line shows the part that was blown away.

The heights are given in metres.

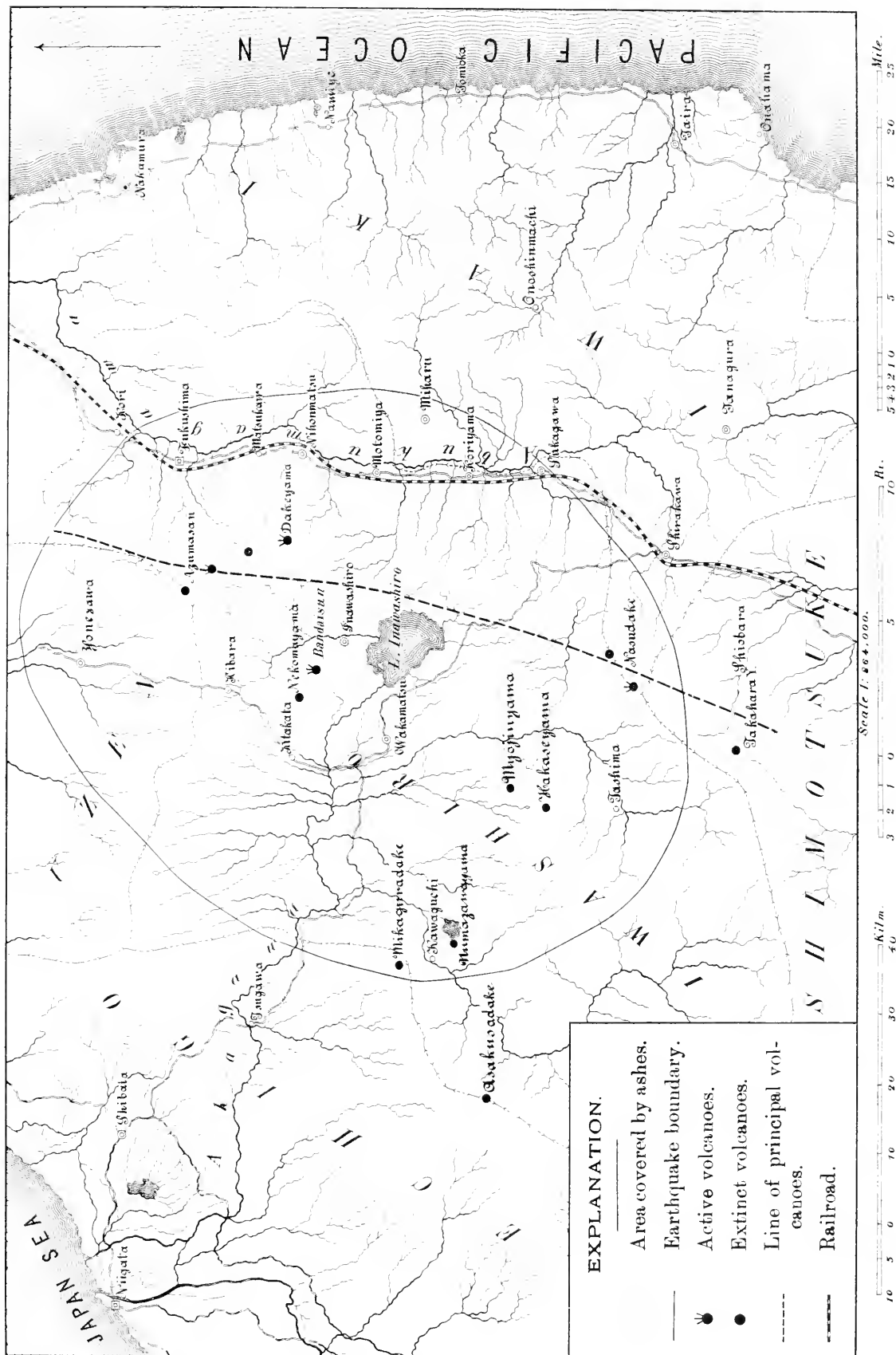
*Plan.*



*Section.*









## ERRATA.

Error in Paging : Page Numbers 209-10 omitted by mistake.





# On Magnetic Lagging and Priming in Twisted Iron and Nickel Wires.

By

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In 1886, Professor Wiedemann published some very interesting experiments on the effects of twist on iron and nickel wires, variously magnetised.\* These, however, were in themselves too few to guide us to any very clear knowledge of the relations of magnetism and twist. A consideration of them at once suggested innumerable lines of enquiry, and opened up vast gaps in our knowledge which prolonged experiments alone could fill. Shortly put, here is an iron or nickel wire of certain dimensions, magnetised in a certain manner either permanently or temporarily, and subjected to a particular straining involving twist. The problem is to find how all these different possible variable quantities or qualities depend on one another.

With a view to work out some small part of this huge problem, I sketched out a line of research, which was partly carried through in 1887 by Mr. K. Imagawa, a graduating student of Physics in the Imperial University of Japan. During the first six months of that year, many distinct series of experiments were made.

The complete discussion of these and other experiments carried

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\* See Wiedemann's *Annalen*, Vol. XXVII., p. 377; translated in the *Philosophical Magazine* (1886).

out later forms a part of a series of papers on the relations of magnetism and twist which I am communicating to the Royal Society of Edinburgh. In the present note I wish to call special attention to one point, namely the character of the lag in magnetic change due to twisting. The peculiarity discovered by Mr. Imagawa was that, for a particular amount of cyclic twisting, the curve showing the corresponding changes in magnetic moment of the twisted wire, if regarded as an area gone round in the proper direction, changed its algebraic sign. This Mr. Imagawa established for iron and nickel wires, circularly magnetised by a current passing along them, and also for nickel wire longitudinally magnetised by a current passing in an enclosing helix of wire. Nearly all the experiments were made with circularly magnetised wires; and the few experiments with longitudinally magnetised nickel were made with the view of finding if the same curious reversal of magnetic lag was obtained with it. By a strange oversight Mr. Imagawa did not observe at the time that circularly magnetised iron wire showed the same peculiarity as nickel; consequently he did not search for an analogous effect in longitudinally magnetised iron. It was only when I came to collate the results of all his experiments that the reversal effect was found to exist also in the case of iron. By that time, however, the various effects of twist on longitudinally magnetised iron and nickel wires had been elaborately investigated by Mr. Nagaoka, whose paper follows immediately on this one. It is because of the obviously close connection between certain of Mr. Imagawa's observations of two years ago and Mr. Nagaoka's more recent results that I have thought it well to discuss the former in this place.

The particular class of problems proposed for investigation was this: Study the effects of different twists upon the magnetic properties of different wires, along which currents of various strengths are

kept steadily flowing. Obviously the wire is, to begin with, circularly magnetised ; and, if it is isotropic as regards magnetic susceptibility, it should show no longitudinal polarity. It is almost impossible, however, to obtain a wire of magnetic metal free from such polarity. All the usual precautions were taken. The wires were roasted and allowed to cool as they lay perpendicular to the magnetic meridian ; and the wire which was being studied lay horizontally in the same direction : opposite the one end of the wire a magnetometer of the usual mirror device was set ; and the other end of the wire was fixed to the twisting apparatus. In order to avoid jars and jolts, the twist was not applied directly by the hand, but was effected by means of a gearing of toothed wheels. For every complete rotation of the handle worked by the hand, the axle which formed the continuation of the wire moved through a few degrees. At the same time the resistance of the gearing was considerable, so that it was an easy matter to keep the hand working at a fairly uniform speed. In this way the twisting of the wire was effected very gently and gradually.

We know already from Wiedemann's experiments that, when such a circularly magnetised wire is twisted right-handedly with reference to the current flowing along it, it becomes longitudinally magnetised, the magnetic intensity being co-directional with the current in the case of iron wire, but anti-directional in the case of nickel wire. After the wire has been twisted and untwisted repeatedly through a considerable range— $4^{\circ}$  per centimetre in Wiedemann's experiments—a corresponding cyclic variation is impressed upon the longitudinal intensity. From a large positive value at or near the one limit of twist, the magnetic intensity changes to a nearly equal negative value at or near the other limit of twist. The average apparent polarity of the wire, as indicated by the deflections of a magnetometer placed oppo-

site one end, is approximately zero.

The most complete series of experiments made by Mr. Imagawa was with a nickel wire of diameter 0.49 millimetres and length 56.4 centimetres. A current of one-third of an Ampère was kept steadily flowing along it; and the wire was subjected to a succession of definite cyclic twistings, each cyclic twisting being continued until the corresponding magnetic changes went through a steady succession. Very complete cycles were taken for the following total to-and-fro twists of the wire as a whole, namely  $\pm \frac{\pi}{2}$ ,  $\pm \pi$ ,  $\pm \frac{3\pi}{2}$ ,  $\pm 2\pi$ ,  $\pm 8\pi$ . These correspond respectively to twists per centimetre of  $\pm 1^{\circ}6$ ,  $\pm 3^{\circ}2$ ,  $\pm 4^{\circ}8$ ,  $\pm 6^{\circ}4$ , and  $\pm 25^{\circ}6$ . The numbers are given in Table I., and are represented graphically in Plate XXV.

The first column on the left gives either in ordinary degrees or in multiples of  $\pi$  the successive stages of the twisting, beginning with the greatest negative twist. The second column gives, in approximately C. G. S. electromagnetic units, the corresponding longitudinal magnetic intensities of the twisted wire from the greatest negative twist to the greatest positive twist. The third column, which should be read from below upwards, gives the intensities as the wire is, so to speak, untwisted from the greatest positive twist to the greatest negative twist. The fourth column is obtained by subtracting the numbers in the third column from the corresponding numbers in the second. The algebraic sign of these differences shows the character of the magnetic lag. Any given algebraic sign applies to all numbers below it, until a number is reached which has the opposite sign.

**Table I.**

(Date of Experiment: April 18 &amp; 19th, 1887.)

TOTAL TWIST.	LONGITUDINAL INTENSITY.		MAGNETIC LAG.
— 90°	+ 74.4	+ 74.4	0
70	66.3	59.8	+ 6.5
50	55.8	42.5	13.3
30	38.4	21.4	17
10	17.4	— 2.5	19.9
+ 10	— 6.2	— 24.8	18.6
30	30.1	42.8	12.7
50	47.4	57.0	9.6
70	63.2	68.2	5
90	76.3	76.3	0
— 180	+ 142.3	+ 144.8	— 2.5
150	134.2	132.1	+ 2.1
120	120.3	116.9	3.4
90	101.1	95.8	5.3
60	71.6	72.9	— 1.3
30	35.7	37.2	1.5
0	— 6.5	— 1.9	4.6
+ 30	45.9	44.0	1.9
60	79.4	77.5	1.9
90	102.3	107.3	+ 5
120	120.9	123.4	2.5
150	137.6	137.3	— 3
180	146	146	0
— 270	+ 194.4	+ 192.8	+ 1.6
225	183.5	184.1	— .6
180	164.3	173.6	9.3
135	137.3	150.7	13.4
90	98	122.8	23.8
45	40	84.9	44.9
0	— 26.4	29.1	55.5
+ 45	81.5	— 37.8	43.7
90	119	97.3	21.7
135	154.1	138.3	15.8
180	171.4	162.8	8.6
225	187.2	178.9	+ 1.7
270	191.6	191.6	0

**Table I.** (*Continued.*)

TOTAL TWIST.	LONGITUDINAL INTENSITY.		MAGNETIC LAG.
— 360°	+ 210.8	+ 211.4	— .6
270	191.0	206.2	15.2
180	138.6	187.2	48.6
90	41.5	153.8	112.3
0	— 73.8	88.0	161.8
+ 90	151.3	— 31.0	120.3
180	187.9	123.9	5.4
270	198.1	190.3	7.8
360	213.3	213.3	0
— 8 $\pi$	+ 244.6	+ 190.7	+ 51.9
7	213.9	192.8	21.1
6	144.2	191.3	— 47.1
5	53.9	190.0	136.1
4	— 12.7	186.6	199.3
3	65.7	182.9	248.6
2	111.6	174.5	286.1
1	147.3	163.7	311
0	172.1	147.6	319.7
+ 1	189.7	122.5	312.2
2	202.1	93	295.1
3	210.5	49.6	260.1
4	215.8	0.3	216.1
5	217	— 67	150
6	218.6	143.5	75.1
7	218.6	198.4	20.2
8	219.2	219.2	0

The curves corresponding to these numbers are shown in Plate XXV., Fig. A. The arrows at the ends of the curves indicate the directions in which they are to be gone round. Thus the curve for twist  $\pm \frac{\pi}{2}$  is to be gone round clock-wise. In it, as shown by the

algebraic sign of the numbers in the fourth column of Table I., there is true magnetic lag. That is, the magnetic change lags behind the strain which causes it. The curve is distinctly open. Passing to the twist  $\pm \pi$ , we see that the magnetic lag is sometimes positive, sometimes negative, but is in all cases very small. Hence the curve can hardly be called open, the going and returning branches being nearly coincident. On the whole, however, as we may see by adding the "lag" numbers, the lag is still positive. This twist may be regarded as being almost exactly the critical twist at which the magnetic lag changes sign; for in the next curve, that for twist  $\pm \frac{3\pi}{2}$ , the "lag" numbers are nearly all negative and markedly so. In fact for this and for higher twists the phenomenon ceases to be one of lagging, but becomes really a case of what might be called magnetic "priming." That is, the magnetic change, as it were, runs ahead of the straining that causes it. In other words, the rate at which the longitudinal magnetic intensity, whether positive or negative, falls off during untwisting from either limit to zero is greater than the rate of growth during twisting. It will be noticed that the curves for the higher twists are of the same character as the one given by Wiedemann (*Annalen d. Phys. u. Chem.*, Bd. XXVII., Taf. III., Fig. 8.).

In Figure A, as given, the curve corresponding to the twist  $\pm 8\pi$  is not shown to the same scale as the others. It is represented to the right as a dotted curve, with the scale of twist diminished to one-eighth and the scale of intensity diminished to two-fifths. The greater openness of the curves for the higher twists, after the critical twist has been passed, is very striking. At the same time it is to be noticed that the range of intensity reaches a practical limit at a very moderate twist. These peculiarities are well shown in Table II. and in Figures B and C which illustrate it.



In Table II., the first column gives the different cyclic twists; the second column the total ranges of intensity, and the third column numbers proportional to the areas of the closed cyclic curves. These areas are easily calculated from the differences given in the fourth column of Table I, and are in fact the best indicators of the nature and magnitude of the magnetic lagging or priming.

**Table II.**

TWIST.	RANGE.	AREA $\div \pi$
$\pm \frac{\pi}{2}$	150.7	+ 11.5
$\pm \pi$	289.5	+ 1.8
$\pm \frac{3\pi}{2}$	385.2	- 58.9
$\pm 2\pi$	424.4	- 260.3
$\pm 8\pi$	437.2	- 2804.7

Curve B shows how the range depends on the twist. The increase is rapid and nearly steady for the small twists; but for higher twists than  $\pm 2\pi$ , the rate of increase of range becomes very small. It should be mentioned that this point was very fully investigated by Mr. Imagawa; and that the conclusion just stated does not rest merely on these five particular cases.

Curve C shows the march of the area of the cyclic curve with the twist. Thus the area begins positive at the low twists, indicating true magnetic lagging. For a twist a little greater than  $\pm \pi$ , the area changes sign, so that we have magnetic priming. For higher twists the area goes on increasing at a very rapid rate. So far as the experiments were carried there seems to be no limit to the increase of

this area. An incomplete cycle for  $\pm 20 \pi$  indicates an approximate area of  $10,000 \pi$ . At these very high twists, the wire must of course be severely strained; the great regularity of the magnetic effect is, in the circumstances, all the more remarkable.

With these results before us, a very natural enquiry was as to the existence of similar peculiarities in the case of longitudinally magnetised nickel wire. Mr. Imagawa had time only for a few experiments, but these were enough to establish the existence of the peculiarity. The most complete results of these experiments are given in Table III. The first column gives the twists in ordinary degrees or in multiples of  $\pi$ ; the second and third columns give, as in Table I, the going and returning measurements of the magnetic condition of the wire; and the fourth column gives the differences between the corresponding numbers in the second and third columns. The numbers are not given in absolute measure, but simply in terms of the scale unit.\* The wire used was 0.85 millimetres in diameter and 52 centimetres in length. Thus the twists as given correspond to twists per centimetre of  $\pm 0^{\circ}58$ ,  $\pm 0^{\circ}87$ ,  $\pm 1^{\circ}16$ ,  $\pm 1^{\circ}73$ ,  $\pm 2^{\circ}32$ ,  $\pm 3^{\circ}47$ ,  $\pm 6^{\circ}94$ ,  $\pm 17^{\circ}3$ .

The results are graphically shown in Plate II., the twists being taken as abscissae and the relative intensities as ordinates. All the curves are double-looped, and are nearly symmetrical for the higher cyclic twists. For the first five cycles, namely,  $\pm 30^{\circ}$ ,  $\pm 45^{\circ}$ ,  $\pm 60^{\circ}$ ,  $\pm 90^{\circ}$ ,  $\pm 120^{\circ}$ , there is true magnetic lag, the return curve at either limit always being above the other. In the curve for  $\pm 180^{\circ}$ ,  $\pm 2 \pi$ , and  $\pm 5 \pi$ , however, the magnetic lag becomes negative. This change in algebraic sign is also shown by the signs of the numbers in column four of Table III, as will be at once seen

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\* Mr. Imagawa has, indeed, left no record of the constants of the magnetising coil which he used, so that it is impossible to reduce the numbers to absolute measure. So far as the present discussion is concerned, this is, however, of no real importance.

**Table III.**

(Date of Experiment. May 31st, 1887).

TOTAL TWIST.		LONGITUDINAL INTENSITY.		MAGNETIC LAG.	
+	30°	256·2	255·8	+	0·4
	20	256	255	+	1·0
	10	255·9	256·8	—	·9
	0	257·2	258·4	—	1·2
—	10	258·4	261·6	—	3·2
	20	260·9	264·2	—	3·3
	30	265·7	265·7		0
+	45	273·5	274·4	—	0·9
	30	272·6	267·9	+	4·7
	15	271·5	268·8	+	2·7
	0	273·4	275·2	—	1·8
—	15	275·3	282·7	—	7·4
	30	281·6	288·9	—	7·3
	45	292·2	292·2		0
+	60	290·1	288	+	2·1
	40	286·4	274·7	+	11·7
	20	280·8	272·4	+	8·4
	0	274·7	281	—	6·3
—	20	277·9	292·9	—	15
	40	282·1	303·1	—	11
	60	308·5	308·5		0
+	90	316·1	317	—	0·9
	60	309·9	300·9	+	10
	30	294·4	271	+	23·4
	0	272·6	278·2	—	5·6
—	30	278·7	305·1	—	26·4
	60	306·4	322·6	—	16·2
	90	329·9	329·9		0

**Table III.** (*Continued*)

TOTAL TWIST.	LONGITUDINAL INTENSITY.		MAGNETIC LAG.
+ 120°	333·4	333·5	— 0·1
90	327·2	319·5	+ 7·7
60	312	296	+ 16
30	284·6	268	+ 16·6
0	259	259·6	— 7·6
— 30	272	288·5	— 16·5
60	300·6	317·7	— 17·1
90	325	333·4	— 8·4
120	339·2	339·2	0
+ 180	339	338·1	+ 0·9
135	328	329·5	— 1·5
90	297	318	— 21
45	254·5	274·6	— 20·1
0	244·5	242·2	+ 2·3
— 45	278·8	251·5	+ 27·3
90	313	298·7	+ 14·3
135	332	329	+ 3
180	341·5	341·5	0
+ 360	345·6	344·3	+ 1·3
270	310·6	344·5	— 33·9
180	244·5	340	— 95·5
90	247·8	324	— 76·2
0	297·4	292	+ 5·4
— 90	331	248	+ 83
180	347	248·5	+ 98·5
270	352	315·5	+ 36·5
360	352	352	0
+ 5 $\pi$	340	344	— 4
3 $\pi$	247	346·5	— 99·5
$\pi$	334·5	344·7	— 10·2
— $\pi$	351	324·4	+ 26·6
3 $\pi$	349	240	+ 109
5 $\pi$	347·6	347·6	0

if the numbers for  $\pm 120^\circ$  and  $\pm 180^\circ$  are compared. Thus, somewhere between these two twists just named, there is a critical twist for which the wire would probably show no magnetic lag at all. It will be noticed how the curves open out as the twists are taken higher and higher. They open out much more rapidly than they appear to do in the Plate; since, for convenience of representation, the curve for  $\pm 360^\circ$  is plotted to half-scale as regards twist, and the curve for  $\pm 5\pi$  (shown dotted in the diagram) to a quarter scale. Here also, as in the curves for the circularly magnetised wire, the range of variation of the magnetic intensity increases rapidly with the twist for small twists, but comes practically to a limit just about the critical twist for which the magnetic lag vanishes. In a series of similar experiments on permanently magnetised nickel wire, Mr. Iwagawa failed to obtain any indication of change of sign. The permanent magnetism rapidly diminished as the twistings were taken larger and larger; the range during twisting reached a distinct maximum for a twist of  $\pm 90^\circ$ , and then rapidly fell off, so that for a twist of  $\pm 360^\circ$  it was hardly measurable. But throughout, the magnetic lag was always positive.

I now pass to the results for iron. Some of these are given in Table IV, arranged exactly as were the numbers for nickel in Table I. It hardly seems necessary to give the curves. Enough to say that they are very smooth, very similar in general outline to the corresponding curves for nickel, but differ from these in being so to speak their inversion, such as would result from reflection in a plane mirror. The numbers in the fourth column are obtained by subtracting the second column from the first, so that for true lag the differences are positive. The wire used was 58 centimetres long and 0.64 millimetres in diameter. The current along the wire was 1.4 ampères. The intensities are given in approximately absolute electromagnetic units (C. G. S.)

**Table IV.**

(Date of Experiment. March 4-7, 1887.)

TOTAL TWIST.	LONGITUDINAL INTENSITY.		MAGNETIC LAG.
- 90°	- 184	- 183	+ 1
60	180	135	45
30	170	51	119
0	149	+ 93	242
+ 30	92	151	243
60	+ 61	173	112
90	184	184	0
- 180	- 318	- 314	+ 4
120	315	262	53
60	306	141	165
0	258	+ 184	442
+ 60	16	295	311
120	+ 233	320	87
180	325	325	0
- 270	- 348	- 345	+ 3
180	352	309	43
90	340	193	147
0	270	+ 190	469
+ 90	+ 120	329	209
180	289	352	63
270	- 351	351	0
- 540	- 384	- 387	- 3
360	391	386	+ 5
180	307	362	- 55
0	+ 224	199	- 423
+ 180	359	+ 314	- 45
360	382	388	+ 6
540	383	383	0
- 720	- 392	- 384	+ 8
540	395	386	+ 9
360	391	382	+ 9
180	+ 215	373	- 588
0	363	332	- 695
+ 180	386	95	- 481
360	392	+ 311	- 81
540	392	394	+ 2
720	386	386	0

As in the case of nickel, so here, the magnetic lag is positive for the smaller and negative for the higher twists. The change of sign occurs, however, at much higher values of twist. In Table V. we see the relations between the twist, the range of intensity, and the area of the cyclic curve, clearly shown. Others are included than those given in Table IV.

**Table V.**

TWIST.	RANGE.	AREA $\div$ $\pi$
$\pm 45^\circ$	94	+ 149
$\pm 90^\circ$	368	127
$\pm 135^\circ$	530	247
$\pm 180^\circ$	641	353
$\pm 225^\circ$	666	387.5
$\pm 270^\circ$	704	467
$\pm 540^\circ$	779	— 513.5
$\pm 720^\circ$	789	— 1821

Thus, exactly as in the case of nickel, the range very soon approximates to its limiting value, while the area, once the critical twist is passed, seems to grow rapidly as the twist increases.

An interesting feature of the iron curves at the high twists is that the greatest and least intensities do not occur at the limiting twists. In other words, the curves have a distinct S shape with true maximum and minimum points. This feature appears first in the experiment for the twist  $\pm 135^\circ$ , for which the full numbers are not here given; but it does not become distinct and undoubted at both limits of twist until the twist of  $\pm 270^\circ$  is attained. Thereafter it is an invariable feature.

In seeking for an explanation of these phenomena of magnetic lag, we must bear in mind the essential difference between experiments in which the mechanical strain is the cause of magnetic change and those in which magnetising force is the cause. Take for example the

well-known case, so frequently discussed, of a wire subjected to a continuously varying longitudinal field. Here in virtue of magnetic retentiveness, there is always true magnetic lag as the field is diminished from its highest value. The magnetic force is, in part, simply removed. But when the wire is twisted through a large angle, the effect of untwisting the wire is no mere *removal* of twist, but is really a *superposition* of an opposite twist. Now, we know that the induced magnetism due to a given field is apparently destroyed by a reversed field of smaller value. It is this effect, rather than the effect of mere diminution of the field to zero, that is to be compared to the effect of untwisting, especially if it is untwisting from a large twist. If the twist is small, however, that is, not greatly beyond the limits of torsional elasticity, the untwisting will be aided by the elasticity of the wire, so that it will have something of the character of a mere undoing. From this point of view, then, small twistings and untwistings will be to a certain extent comparable to applying and removing magnetising force; while large twistings and untwistings are to be compared rather to applying first a given magnetising force and then a small reversed magnetising force. Hence for small cyclic twistings, the magnetic lag is a true lagging effect; but for large cyclic twistings it becomes really a "priming" effect. The fact that the limits of torsional elasticity for iron are much greater than the same for nickel fits in admirably with the result established above that the critical twist at which the lag changes sign is much higher for iron than it is for nickel.

There is, however, another and perhaps a simpler explanation of the phenomenon. It is suggested by some results of experiments of the same nature which I have carried out very recently. The experiments are not quite completed; but enough has been done to show that, in the case of nickel (and in certain circumstances, iron also)



magnetised circularly by a current passing along it, the *positive* lag is eliminated if the wire is tapped or kept in a state of forced vibration. Thus it may be that the tendency of cyclic twisting is to produce negative magnetic lag; but that the effect is modified by the magnetic retentiveness of the undisturbed wire, a retentiveness which is generally explained in terms of molecular friction.

The two explanations suggested are not altogether rivals. It is quite possible indeed, that both may be true, being simply somewhat different ways of looking at the phenomena involved.



# Effect of Twist on the Magnetization of Nickel and Iron.

By

H. Nagaoka, *Rigakushi*,

of the

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Plate XXVII.

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The present paper is a continuation of one published some time ago under the title 'Combined effects of torsion and longitudinal stress on the magnetization of nickel.'\* The results there described were only for a single specimen of nickel, and moreover the range of twist to which the wire under examination was subjected was always the same, namely,  $\pm 4.5$  per cm. length of the twisted wire. The main facts established in that paper were as follows:—

When the nickel wire is twisted in a constant magnetizing field, the magnetization curve obtained during torsion and detorsion undergoes a gradual transformation as the amount of longitudinal stress acting on the wire is increased. Under low tensions, the magnetization increases on twisting, and decreases on untwisting. The nature of the hysteresis is such that the ascending branch of the curve is always above the descending branch, and the curve is quite symmetrical on both sides of zero twisting. On increasing the longitudinal stress, the magnetization curve becomes gradually deformed, while at the same time, there is great decrease of magnetization. Eventually when the loading reaches a certain value, one end of the wire acquires

\* See this Journal Vol. II, pg. 283.

reversed polarity, and the curve which was double looped transforms into a single looped curve.

Now the question naturally suggests itself, can this curious phenomenon of the reversal of polarity as well as other remarkable characteristics in the magnetization of nickel be still observed in wires taken from different sources, and also for different angles of twist? The objects of the experiments now to be described are to fill in these gaps, and also to extend the investigation to the case of iron.

The method of procedure was exactly the same as in the former experiments. The intensity of magnetization was measured by the direct magnetometric method from the amounts of deflection of a magnetometer mirror. The wire was placed vertically within a solenoidal coil, and its upper end was magnetic east of the magnetometer mirror. A constant magnetic field was maintained within the solenoid; and as the wire was subjected to the given cyclic twisting, the deflections on the magnetometer scale were noted. The twist was applied by means of the twisting apparatus described in the former paper. The effects were examined for two specimens of nickel wire obtained from different manufacturers. They were of different diameters, being 0.86 mm. and 1 mm. thick respectively. The latter was the one used in earlier experiments. Each wire studied was first annealed by gently passing it over the flame of a spirit lamp three or four times.

As the object of the investigation was merely to examine the changes of magnetization, I have not thought it necessary to reduce the observed readings to absolute units; and consequently the numbers given are simply in terms of the scale unit. The reversal of polarity and other accompanying changes are so complicated that I have examined only a few particular cases, and most of the experi-

ments for nickel were performed under low tensions. The effects of torsion on magnetization are much simpler for iron than for nickel, yet in both there exists quite a curious change in the hysteresis as will appear hereafter.

### Effect of Twist on the Magnetization of Nickel.

The effect of cyclic twisting on the magnetization of nickel wire is itself a function of the magnetizing field and of the range of twisting, and passes through a distinct gradation of changes as this range is gradually increased. For small twists these changes are marked by many peculiar and interesting characteristics; and most of my experiments are limited to cases in which the twist is not very large. To examine the effect of longitudinal stress on the magnetization for each range of twist and for each magnetic field would be a matter of immense labour. I have therefore examined only a few cases in which the load was varied, and have noted some of the general features.

*Changes of magnetization for the twist of  $\pm 0.86$ .*—The smallest amount of twist producing changes in magnetization, which could be measured with certainty, was about 0.9 per cm. A nickel wire, 0.43 mm. in radius and 35 cms. long, was well annealed, and placed in position, the longitudinal stress acting being only the weight of the small twisting rod and the brass wire connecting this rod to the lower extremity of the nickel wire.

The first experiment was performed in a field of 0.34 (C.G.S. electro-magnetic unit). The wire was twisted through  $\pm 30^\circ$  (0.86 per cm.) on both sides of the initial unstrained position. After the changes in magnetization became cyclic, the following readings of the deflections were taken.

Twist (positive).	Deflections.	Twist (negative).	Deflections.
0°	112.5	0°	109.5
10	107.4	10	110.4
20	110.1	20	120.0
30	121.1	30	132.4
20	117.9	20	128.8
10	113.0	10	122.2
0	109.5	0	113.7

The examination of the curve (Fig. 1, Plate XXVII.) will shew that on twisting the wire in the positive direction, there is a slight diminution of magnetization till the angle of twist amounts to about  $10^\circ$ , then the magnetization gradually increases up to  $30^\circ$ . On untwisting, the magnetization diminishes, but at a somewhat slower rate than it had just been increasing, so that the return curve lies above the other until the wire is nearly all untwisted. The same things happen during negative twisting and untwisting. Thus in the present instance, the course of the change of magnetization is quite different from what was obtained in my former experiments under like circumstances. There I found that when the nickel wire was twisted  $\pm 4.5$  per cm., the magnetization rose gradually till the maximum twist was reached, but on untwisting diminished at a somewhat quicker rate than it had just been increasing, so that the return curve lay below the other.\*

*Reversal of hysteresis.*—Comparing these two experiments, we find that there is true lagging or hysteresis in magnetization when the

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\* In my former paper, I spoke of Fig. 5 (Pl. XVI.) as being exactly the reverse of Thomson's curve for iron, but I was mistaken; had the course of the curve been as for the twist of 0.86, it would have been so, but not otherwise.

Compare also Professor Wiedemann's curve (Fig. 4) in his paper *Magnetische Untersuchungen* (Wied. Ann., Bd. XXVII, 1886).

range of twist is small, but that when the range is large there is a 'priming' in magnetization rather than a lagging.\* Now we are quite warranted in using the word hysteresis in both senses, just as acceleration in dynamics includes retardation. We may speak of positive and negative hysteresis; and express the phenomenon just described as a reversal of hysteresis, occurring probably at some twist intermediate to the two just named. How this reversal of hysteresis is affected by various conditions such as the quality of nickel, the strength of the magnetizing force, the amount of twist, &c., is a very obvious matter for investigation.

*Effect in stronger fields.*—With the same wire and other conditions being the same, the field was taken stronger and stronger. Very similar effects were obtained as may be seen from Fig. 2, which corresponds to a field  $H=11.9$ . In Fig. 3, however, a change begins to shew itself. The field is now 13.8, and the particular wire examined was a new piece cut from the same specimen. It will be noticed that the range of change is much diminished, but that the character of the hysteresis is still the same as before. When the strength of the magnetizing force is increased to 18.7 units, the magnetization curve (Fig. 4) wears quite a different aspect. On first twisting, the magnetization diminishes as in the former cases, but it never passes a minimum, although the rate of fall becomes very slow towards the limit of twist. On untwisting, there is gradual increase of magnetization, but it is always smaller for the same angle of twist, than it was during the operation of twisting. Thus there is hysteresis in the proper sense of the word. Further twisting in the opposite direction produces a similar succession of changes, although the curve is not quite symmetrical about the line

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\* I was not aware, until my own experiments were all completed, that this phenomenon had been observed by Mr. Imagawa. See the preceding paper, by Dr. Knott.

of zero twist. The curve of magnetization for stronger fields (Fig. 5) are similar to the above, the range of the change of magnetization becoming apparently greater as the magnetizing field is increased.

*Reversal of polarity for the twist of  $\pm 0.86$ .*—The next wire used was taken from the same specimen as before. A weight of 5 kgs. (881 kg. cm.<sup>-2</sup>) was strung to the end of the brass wire attached to the lower extremity of the nickel wire. After the wire was brought to the cyclic condition by repeated torsion and detorsion in a field of 0.34 unit, the following deflections were taken.

Twist (positive).	Deflections.	Twist (negative).	Deflections.
0	11	0	10
10	2	10	19.5
20	— 8	20	29
30	— 17	30	41
20	— 9	20	33
10	0.6	10	23
0	10	0	11.5

These readings shew that, in the given field, the amount of longitudinal stress was sufficient to produce the phenomenon of reversed polarity. The magnetization curve (Fig. 6) when compared with the corresponding curve for the twist of  $\pm 4^{\circ}.5$  again indicates how the changes of magnetization differ in these two cases. In former experiments, there was always increase of magnetization on first twisting, and decrease on untwisting, the hysteresis being negative. In the present instance, there is steady decrease of magnetization during positive twisting, and increase during untwisting. Besides, as the twist at either extremity begins to be undone, the magnetization lags behind, so that the hysteresis is positive.

These experiments sufficiently prove that the reversal of polarity

takes place in different specimens of nickel, and also for different amounts of twist. The curve representing the changes of magnetization when the polarity suffers reversal is, as already noticed, single looped, whereas we get double looped curves in cases where there is no reversal of polarity, that is, in cases in which the longitudinal stress is sufficiently weak. Hence in the present case we should expect that, by gradually increasing the magnetizing force, until the longitudinal stress of 5 kgs. weight is insufficient to cause reversal of polarity, we shall be able to transform single looped into double looped curves. The experiment when made fulfilled the expectation, as may be seen from Fig. 7. Here the field is 5.0 units: the curve has ceased to dip below the zero line so that the polarity is not reversed. At the same time, the curve, though unsymmetrical with respect to the line of zero twisting, turns out to be double looped. On further increasing the field the two loops become more and more symmetrical (see Fig. 8). Thus the question as to whether a given curve will be single looped or double looped seems to depend on the existence or non-existence of the phenomenon of the reversal of polarity. What has been stated in my earlier paper with respect to the form of the magnetization curve for the twist of  $\pm 4^\circ.5$  per cm. is also applicable for that of  $\pm 0^\circ.86$  per cm. There is, however, a remarkable difference in the change of magnetization which may be expressed by saying that there is reversal of hysteresis between these two different twists.

*Reversal of hysteresis for the twists of  $\pm 1^\circ.5$  and  $\pm 1^\circ.3$ .*—In the next series of experiments, the twists were taken larger. A wire 40 cms. long and 1 mm. thick was set in various magnetizing fields, and twisted through a total range of  $\pm 60^\circ$  or through a twist of  $\pm 1^\circ.5$  per cm. The only longitudinal stress acting was the weight of the twisting rod and the brass wire attached to the end of the



nickel wire. Out of the many curves obtained in this series, I give only three, those namely which correspond to fields of 2.8, 15.3, 21.1 units respectively. The first two curves (Fig. 9 and Fig. 10) have the same characteristics as those obtained for nickel twisted through  $\pm 0^\circ.86$  per cm. There is still true lagging on untwisting. But the third curve (Fig. 11) for  $\mathfrak{H}=21.1$  is not similar to the corresponding curves represented in Fig. 7 and Fig. 8. The curve in its general form is like those obtained for smaller twists, but the nature of the hysteresis has been changed. The hysteresis which has been positive for the two former curves becomes negative for this strength of the magnetizing force. The magnetization diminishes on twisting till the extreme limit of torsion is attained, and on untwisting it gradually increases. If the magnetization had tended to lag behind, as was found to be the case for the smaller twist, the return curve would have been the lower. But this is no more the case: the curve on untwisting passes above that of twisting, and thus there must have been reversal of hysteresis for this strength of the magnetizing force. It is at once apparent that the strength of the magnetizing field is one of the principal factors affecting the phenomenon of the reversal of hysteresis.

In order to investigate this change more thoroughly, a new wire was taken from the same bundle, and examined in fields  $\mathfrak{H}=16$  (Fig. 12) and  $\mathfrak{H}=20.8$  (Fig. 13). The former curve shows that there is decrease of magnetization up to a certain amount of twist, but on further twisting there is increase. This increase, however, is so small that it is barely sufficient to attain the original intensity even at the extreme limit of twist. On untwisting, the magnetization gradually diminishes but increases again, passing through a minimum value before the wire is completely brought back to its initial position. This peculiarity of a minimum on untwisting had never been

noticed before for the smaller twists. On increasing the field to 20.8 units, another change takes place in the magnetization curve. The points of minimum magnetization on both twisting and untwisting have vanished altogether, the magnetic intensity always diminishing in the former, while it increases in the latter. At the same time, the original double looped curve becomes contorted, and the going and returning curves cross each other. But as soon as this stage is past, the increase of magnetizing force makes the four loops of the magnetization curve collapse into two, and hereafter the curve wears the general aspect as shown in Fig. 11.

*Diminution of magnetization by twisting in strong magnetizing fields.*—The fact that the magnetization diminishes instead of rising when twisted in high magnetizing fields, can be explained from the nature of the curves of magnetization for different twists. In my former paper,\* it was shown that beyond a certain strength of the field, the susceptibility of the twisted wire diminishes more rapidly than that of the untwisted, so that the magnetic intensity is in general smaller for the twisted than for the untwisted. Thus we should be led to expect a diminution of magnetization on twisting, and increase on untwisting, and the curve will have the appearance as in Figs. 7, 8, and 11. But this does not throw any light on the reason for the change of sign of hysteresis between the cases represented by Figs. 10 and 11.

*Reversal of hysteresis occurs in lower magnetizing fields as the twist is taken larger.*—The preceding experiments for the twist of  $1^{\circ}.5$  led me to suspect that the strength of the magnetizing force as well as the amount of twist formed a chief cause of the reversal of hysteresis, and is not due to the difference in nickel. To test this, a thin wire 35 cms. long was twisted through  $\pm 1^{\circ}.7$  per cm. The curve (Fig.

\* Magnetization and retentiveness of nickel wire under combined torsional and longitudinal stresses. This Journal, Vol. II.

14) obtained in  $\mathfrak{H}=0.34$  shews that the nature of hysteresis is similar to the two former results for smaller twists and is the reverse of that for the twist of  $\pm 4^{\circ}.5$  per cm. But in the stronger field of  $\mathfrak{H}=2.4$ , the amount of hysteresis was greatly diminished as may be seen from the curve shewn in Fig. 15. For  $\mathfrak{H}=5.1$ , the deflections were as follows:—

Twist (positive).	Deflections.	Twist (negative).	Deflections.
0°	422	0	426
10	452	10	444
20	483	20	473
30	503	30	497
40	515	40	512
50	522	50	519
60	527	60	524
50	521	50	518
40	512	40	508
30	497	30	492
20	474	20	466
10	441	10	435
0	426	0	422

The curve as plotted in Fig. 16 shews what change has taken place. There is increase of magnetization on twisting till the extreme limit of torsion is attained. On untwisting there is diminution, and, for the corresponding angles of twist, the intensity of magnetization is always less than on twisting. In other words, the magnetization has no tendency to lag behind on untwisting, but rather the contrary. There is negative hysteresis for this particular combination of twist and magnetizing force. In fact the nature of hysteresis is similar to that for the twist of  $\pm 4^{\circ}.5$ , but reverse to any so far obtained for smaller twists in low magnetizing fields. As the magnetizing field is increased, the same order of things comes in, and the course of the

magnetization curve is opposite to what holds in weak fields for the same angle of twist, as will be seen from Fig. 17. These experiments sufficiently prove that the reversal of hysteresis not only depends on the amount of twist, but also on the strength of the magnetizing field, the phenomenon appearing in lower and lower magnetizing fields as the twist is taken greater and greater.

The above statement is confirmed by further experiments made with 1 mm. wire, the range of twist amounting to  $\pm 2^\circ$ . The curve (Fig. 18) for  $\aleph=0.34$  has the course usual for small twists, so that there is true lagging on untwisting. But when the field strength is increased to 7.3 units (see Fig. 19), the going curve lies above the returning curve, and thus the hysteresis turns out to be negative. Thus for this amount of twist, the magnetizing force was sufficient to cause the reversal.

*Form of the curve when the reversal is about to take place.*—One important point still remains to be investigated. We must examine what form the curve takes just as the reversal of hysteresis is about to occur. I had the satisfaction of obtaining the desired curve by subjecting the wire to a twist of  $\pm 2^\circ.5$  per cm. under the action of the vertical component of the terrestrial magnetic force. The curve just on point of reversal (see Fig. 20) is no more double looped, but becomes more complex. Examining the changes of magnetization, we notice that on twisting, there is always increase of magnetization till the extreme limit of twist is reached, while on untwisting, the curve, instead of going below the former path, goes above it for a certain distance but before returning to the line of zero twisting, crosses the course taken in going, and finally passes below it. Thus the curve is four looped. The appearance of four loops marks the transition in the nature of hysteresis, and any further increase of the magnetizing field produces reversal of hysteresis, the curve becoming

again double looped as in Fig. 21.

*Curves for large twists.*—When the range of twist is increased to  $3^\circ$  or  $4^\circ$  per cm., a reversal of hysteresis by increasing the magnetizing force is not obtained. The curves are generally of the same character as those already described for the twist of  $4^\circ.5$ . Even for such large twists as  $9^\circ$  or  $10^\circ$  (see Fig. 22 and Fig. 23) the above remark holds true, the hysteresis being such that the going always passes above the returning curve. To give detailed description on this point would be merely repeating the earlier paper, and I feel no need of entering into the discussion of the results for these twists.

*Effect of twist in strong magnetizing fields.*—Another thing which calls for remark is the behaviour of nickel in strong magnetizing fields, during cyclic twistings. It was already noticed for the twist of  $\pm 1^\circ.5$ , how the magnetization diminishes on twisting, and increases on untwisting and how a particular complexity in the curve precedes the transference into such a state. The same curve of transition is also observed when the amount of twist is so large that the reversal of hysteresis takes place in a low magnetizing field. This is well exemplified in Fig. 24, which was obtained for  $\delta=20.8$  with a thicker wire twisted  $\pm 2^\circ$  per cm. But owing to the reversal of hysteresis, the course of the curve is different as the comparison of Figs. 13 and 24 will shew. The general character of the magnetization curve in strong magnetizing field, during cyclic changes of torsion, is shewn in Fig. 25, which is given as a type of such curves. It was obtained with a wire of 0.43 mm. radius in a field of 24.7. There is constant decrease of magnetization during twisting, and increase during untwisting up to a certain angle of twist, where it reaches a maximum. It then diminishes, and returns to its former value when the wire is brought to the initial position of zero twisting. The intensity of magnetization is always greater during untwisting than

during twisting. It will be afterwards shown that the curve is analogous to that of iron subjected to large twists.

*Reversal of polarity for different twists.*—With regard to the reversal of polarity for different amounts of twists, another set of experiments was performed with a thin wire for a twist of  $\pm 1^\circ.7$  per cm. On loading the wire with a weight of 5 kgs., the longitudinal stress was sufficient to produce the reversal of polarity when placed in the field  $\mathfrak{H}=0.34$ . The magnetization curve thus obtained is represented in Fig. 26. This curve is single looped, and has the same characteristic as those obtained for the twist of  $\pm 4^\circ.5$  in weak magnetizing fields under high tensions. The hysteresis in the present case is negative, and is opposite to that for the twist of  $\pm 0^\circ.86$ . (Compare Fig. 6 and Fig. 26). The difference of hysteresis for these two twists must be due to the difference of twist. To test this more fully, a new wire was placed in the same condition as before with regard to the longitudinal stress and the strength of the magnetizing field, and subjected to two different twists of  $\pm 1^\circ.2$  and  $\pm 1^\circ.4$  respectively. The curve obtained from the former was similar to that for  $\pm 0^\circ.9$ , while the one given by the latter agreed with that for  $\pm 1^\circ.7$ . Thus, for the above longitudinal stress and  $\mathfrak{H}=0.34$ , the reversal of hysteresis must take place between the twists of  $\pm 1^\circ.2$  and  $\pm 1^\circ.4$ . This result indicates that the hysteresis is influenced by the difference of twist although the wire is subjected to high tensions.

The next point to be examined is how the double looped curve is transformed into a single loop when the opposite polarity is about to appear. This interesting point was examined by increasing the strength of the magnetizing force. For  $\mathfrak{H}=2.5$  and  $\tau=\pm 1^\circ.7$ , the opposite magnetism is completely effaced, while at the same time the curve (Fig. 27) becomes double looped. Although the loop formed during positive twisting is very thin, it is quite certain that the

curve becomes double looped simultaneously with the vanishing of the opposite polarity. The newly formed loop gradually widens as the magnetizing force is further increased, as will be seen from Fig. 28. The experiments made for the twists of  $\pm 0.86$ ,  $\pm 1^\circ.7$ ,  $\pm 4^\circ.5$  all show that the cyclic curve of magnetization is gradually transformed from a double looped to a single looped curve, when the wire begins to shew opposite polarity.

Large twists applied to nickel do not seem to affect the phenomenon of reversal of polarity. After observing the changes in magnetization as shown in Fig. 22, I loaded the wire with 1 kgrm. weight. The longitudinal stress thus applied was already sufficient to cause the reversal of polarity and the curve as shown in Fig. 29 was obtained. It is single looped and similar in character to those observed for the twist of  $\pm 4^\circ.5$ . The results thus far obtained by varying the amount of twist from  $\pm 0.86$  to  $\pm 9^\circ$  per cm. prove that the phenomenon of the reversal of polarity always takes place however the twist may vary, provided sufficient longitudinal stress be applied. To examine more particularly into these intricate relations between twist, longitudinal stress, and magnetization would mean an amount of labour, which the importance of the subject hardly seems to merit.

### Effect of Twist on the Magnetization of Iron.

This subject was first investigated by Sir William Thomson, and the experiments to be described are to a great extent merely a repetition of his. The effect of twist on the magnetization of iron is not of so complex a character as it is in the case of nickel. In iron, the effect of the longitudinal stress combined with twist does not produce any reversal of polarity, nor are the changes of hysteresis so intricate as in nickel. But when the twist exceeds a certain limit,

there is the same curious reversal in the hysteresis.

*Repetition of Thomson's experiments.*—I shall first of all describe some of the curves obtained for small amounts of twist, being merely a repetition of Thomson's experiments. An iron wire 0.66 mm. thick and 40 cms. long was well annealed by means of a spirit lamp, and arranged in the same way as the nickel wires had been. The wire was then twisted through  $180^\circ$  in both directions, the strength of the magnetizing field being kept constant. The curves thus obtained during cyclic changes of torsion are shown in Figs. 30 and 31. The former was obtained under weak longitudinal stress in the magnetizing field  $H = 2.9$ . The latter is plotted from observations made in the same field, the longitudinal stress amounting to 1800 kgrms. per sq. cm.

The effect thus produced by twisting iron is not so complex as for nickel, and the change in magnetization is but a small fraction of the whole. The curves obtained under various loads are nearly all similar in shape, and for the most part agree with those given by Thomson.

New experiments were made by using a wire of the same length taken from the same specimen, and twisting it through  $\pm 360^\circ$  ( $\pm 9^\circ$  per cm.). The curves thus obtained in different magnetizing fields are plotted in Figs. 32, 33, 34. The hysteresis in these magnetization curves is such that in the returning branch the curve is lower than in the going branch. The comparison of curves subjected to twists of  $\pm 4.5$  and  $\pm 9^\circ$  will shew that everything remains the same except in a single point. As the twist is increased, the ascending and the descending branches of the curve tend gradually to approach towards each other, although the hysteresis has the same sign in both cases. Thus the amount of hysteresis in iron is affected by different twists, while the increase of the magnetizing force seems to cause no



essential change. If the twist be still more increased, two cases are quite possible; either the going and the returning branches of the curve will continually tend to approach, or the going will ultimately lie below the returning branch, so that reversal of hysteresis will declare itself.

*Reversal of hysteresis.*—To solve this question, a wire 27 cms. long and 0.66 mm. thick was treated in the usual way, and twisted through  $\pm 360^\circ$ . The twist thus applied was very large and amounted to  $13\frac{1}{3}$  per cm. After a number of twistings and untwistings, the following readings of deflections were taken for  $\Omega = 2.9$ .

Twist (positive).	Deflections.	Twist (negative).	Deflections.
0°	487.2	0°	489.8
40	481.7	40	484.0
80	476.8	80	479.3
120	473.4	120	476.0
160	470.0	160	472.2
200	467.2	200	469.8
240	464.1	240	467.0
280	462.0	280	464.8
320	459.9	320	462.9
360	457.3	360	460.8
320	460.0	320	463.3
280	463.8	280	467.0
240	469.2	240	472.0
200	476.8	160	478.7
160	487.5	120	489.6
120	497.6	80	499.7
80	500.7	40	502.4
40	495.9	10	496.8
0	489.8	0	490.9

By examining the curve (Fig. 35) we see that on twisting the wire, there is constant decrease of magnetization, while on untwisting, the magnetization rises steadily till it reaches a maximum, after which it returns to its original value at the initial position of zero twisting. Thus in the returning branch the curve is no more lower than in the going branch, so that the course of the magnetization curve is opposite to that for the twists smaller than and up to  $\pm 9^{\circ}0$ . As was already noticed in nickel, there is also reversal of hysteresis in iron. So far as my experiments go, the strength of the field or the amount of longitudinal stress does not seem to produce any remarkable variation on hysteresis, as the curves (Fig. 36, 37, 38) will shew.

It is thus established that the hysteresis in iron becomes reversed when the range of twist exceeds a certain limit. This must evidently lie between the twists of  $\pm 9^{\circ}$  and  $\pm 13^{\circ} \frac{1}{2}$  per cm. But it is not easy to determine the exact critical twist, even by experimenting for twists intermediate between the two. For a twist of  $12^{\circ}$  per cm, the difference between the going and returning branches of the curve diminishes to a certain extent as will be seen from Fig. 39. For a twist of  $10^{\circ}4$  (Fig. 40) the two branches of the curve are separated by a still smaller interval; but still the former lies below the latter, so that the hysteresis is opposite in character to that for the twist of  $9^{\circ}$  per cm. Judging from these experiments, it can safely be inferred that the curious phenomenon of the reversal of hysteresis in iron takes place when the range of twist amounts to about  $\pm 10^{\circ}$  per cm.

*Comparison of results for iron and nickel.*—Comparing these results for iron with those obtained for nickel, we find some analogy between the two. As was formerly remarked, the changes in magnetization in nickel due to cyclic twistings are opposite in character to those of iron. But when the amount of twist as well as the

strength of the magnetizing force is varied, we find gradual transformations taking place. The magnetization curves in nickel for small twists and weak longitudinal stresses are opposite in character to those in iron for moderate twists. When the twist in nickel exceeds  $1^{\circ}5$  per cm., and the magnetizing force is sufficiently strong, the magnetization curve loses its opposite character to that of iron under moderate twists, and acquires a form similar to that for iron subject to very large twist, as the comparison of Figs. 25 and 39 shews.

*Summary.*—I shall in conclusion summarise the results obtained in the present experiment.

In nickel under feeble longitudinal stress, there is reversal of hysteresis when the range of twist is moderate. This phenomenon takes place in lower magnetizing fields as the twist is increased. When the amount of twist exceeds  $3^{\circ}$  per cm., nothing of this nature is observed. The reversal of polarity, on the contrary, is a phenomenon common to all twists, provided the longitudinal stress applied be sufficiently great.

In iron, so far as my experiments go, the magnetizing force does not alter the character of hysteresis, but reversal of hysteresis takes place when the twist exceeds  $10^{\circ}$  per cm., and the magnetization curve bears a close resemblance to that of nickel in strong magnetizing fields for moderate twists.

The effects of twist in iron and nickel, and especially in the latter, are so complicated that it is impossible to give anything like a true explanation coordinating all these facts. The magnetic qualities of these two metals with regard to stress are generally opposite. Not only do twist and longitudinal stress produce opposite effects in magnetization, but by twisting the wire in the magnetizing field we obtain transient currents in opposite directions for these two metals and

it can scarcely be doubted that these sets of phenomena are closely linked together. The occurrence of a *maximum* current for moderate amounts of twist and other peculiarities will be discussed in a future communication.





# Oxyamidodosulphonates and their Conversion into Hyponitrites.

By

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and

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In our paper on the *Reaction between Sulphites and Nitrites of Metals other than Potassium*, (*J. Ch. Soc.* **51**, 659), we gave notice of our intention to work upon the reactions of the sodium salts. This intention we have carried out, and already find ourselves in a position to materially extend and modify the knowledge of the chemistry of the sulphazotised compounds contained in the writings of our predecessors in the investigation. Fremy\*. Ad. Claus and Koch†, Berglund‡, and Raschig§. We propose to publish our contribution to this large subject in a few short papers, such as the present one, each complete in itself.

*Oxyamidodosulphonates*, the subject of the present paper, are the *sulphazidates* of Fremy, the *sulphydroxylamates* of Claus, the *hydroxylamine-monosulphonates* of Raschig. Between the one set of terms—

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\* *Ann. Chim. Phys.* [3], **15**, 403.

† *Ann. Chem. Pharm.* **152**, 336; **158**, 52 and 194.

‡ *Bull. Soc. Chim.* **25**, 455; **29**, 422; *Ber. Ch. Ges.* **9**, 252 and 1896.

§ *Ann. Chem.* **211**, 161.

*nitrilo-*, *imido-*, and *amido-*, *oximido-* and *oxyamidodisulphonate*, and the other set—*amine-* and *hydroxyamine-tri-*, *di-*, and *monosulphonate*, there is not much to choose by. But as it is desirable on the score of consistency, to employ exclusively one set or the other, the already prevalent use of *nitrilo-*, *imido-*, and *amidodisulphonate* makes it proper to use *oximido-* and *oxyamidodisulphonate* rather than *hydroxyamine-di-* and *monosulphonate*.

*Oxyamidodisulphonic acid*, known only in solution, was first prepared by Fremy, who found that *potassium oximidodisulphonate*, (*neutral-sulphazotate*), sooner or later decomposed into acid-sulphate and the oxyamido-salt, doing so at once when its solution was boiled. Altering his atomic weights to those now accepted, and writing empirically his formulæ, to which he attached no constitutional significance, his equation becomes —



Claus has shown, however, that these formulæ incorrectly represent the composition of the salts, and Raschig has confirmed Claus's statement. The two formulæ corrected and halved stand as  $\text{S}_2\text{O}_9\text{K}_2\text{H}_5\text{N}$  and  $\text{SO}_3\text{KH}_2\text{N}$ , or  $\text{HON}(\text{SO}_3\text{K})_2(\text{OH})_2$  and  $\text{HONH}(\text{SO}_3\text{K})$ , according to Claus. The latter formula we have further to modify slightly.

To get the oxyamidodisulphonic acid pure for preparing its salts, Fremy neutralised with ammonia the hydrolysed solution of potassium oximidodisulphonate, added barium chloride, filtered off sulphate, and then, by adding baryta-water, precipitated a dibarium oxyamidodisulphonate. This salt, when washed, he decomposed by adding just enough sulphuric acid to combine with the barium, and then used the filtered solution of the new acid for combining with bases. The acid appears

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He recognised the peculiarity and importance of this first instance of what we now style the hydrolysis of a sulphonate into a sulphate.

to be the only sulphonyazotised acid possessing any stability. Claus introduced the slight modification of Fremy's process for preparing it of omitting the preliminary neutralisation with ammonia.

Having discovered a second barium salt, neutral and soluble, we proceed differently in treating the barium precipitate, and thereby avoid the contamination of the salts with sulphite, always present in Fremy's barium precipitate (see the section of this paper headed, *the decomposition of oxyamidosulphonates by alkaline bases*). The dibarium salt is, as found by Fremy, very alkaline to litmus, and we add to it only enough sulphuric acid to get a neutral solution, along with barium sulphate equivalent to half the barium and such barium sulphite insoluble as may have been present in it. The solution contains only monobarium oxyamidosulphonate and from it can be prepared the acid and its salts by adding its equivalent of sulphuric acid or a sulphate, to determine which, an estimation of barium is made in a portion of the solution.

Raschig prepares an impure acid from Fremy's solution obtained by boiling potassium oximidosulphonate so as to hydrolyse it into potassium sulphate and oxyamidosulphonate. To do this he removes the potassium sulphate by alcohol and then concentrates the solution of the acid to a syrupy consistence.

*Sodium oxyamidosulphonate*, prepared by Fremy and by us, is a clear gummy liquid as thick as molasses, which exposed over sulphuric acid (in a partial vacuum) never solidifies or shows any sign of crystallisation. It is neutral in reaction.

*Potassium oxyamidosulphonate*, prepared and analysed by Fremy, by Claus, and by us. It occurs in six-sided plates as stated by Fremy, when crystallised from its hot solution, but the plates are more often square, while by spontaneous evaporation of its cold solution thick tables and bold prisms are obtained. Claus found the



crystals to be anhydrous, and Fremy's analysis and formula agree with this finding. But it is now known that Fremy's analytical results cannot be relied on, and we have already had to give an instance of this in the present paper and shall have to give others. Differing from Claus, we find all the crystals of this salt to effloresce slowly over sulphuric acid, and to give on analysis results indicating the presence of one molecule of water. Solutions show a great tendency to supersaturate, and it becomes often quite difficult to crystallise them. When thoroughly dry the crystals can be kept for months without undergoing much change, but moist they are unstable, hydrolysing and becoming acid to litmus. The acidity developed is that of hydroxyammonium sulphate, hardly showing with methyl-orange. Heated they suddenly intumesce below  $100^{\circ}$  and thoroughly decompose.

To determine the sulphur and nitrogen we hydrolysed the salt in a sealed tube with hydrochloric acid at  $130^{\circ}$  C., here following Raschig's process, which gives, however, somewhat irregular results as we afterwards found (see the analysis of the dibarium salt). The hydroxyamine thus produced was measured by iodine after addition of potassium acid-carbonate. Water could not be removed by exposure over sulphuric acid at the ordinary temperature and pressure rapidly enough to be convenient for analytical purposes, this and other sulphazotised salts retaining, according to our experience, part of their crystallisation-water with great tenacity. Nor could the water be well expelled in the oven, because of the decomposition of the salt at about  $95^{\circ}$ . But we made a fairly good estimation of it, by moderately heating the salt in a Sprengel-pump vacuum, in a long bulbed tube containing also sulphuric acid. The following is a table of our results—

	$\text{HONH}(\text{SO}_3\text{K})_2\text{OH}_2$	<i>a</i>	<i>b</i>	<i>b</i>
Potassium	23.08	22.53*	23.45	
Sulphur	7.58	7.34	7.69	7.56
Oxyamidogen. $\text{HONH}$ .	18.94	17.96	19.76	17.50
Water	10.39		9.29	

Sample *a* was in prisms, and *b* in tabular crystals. We have given much consideration to Claus's apparently carefully obtained results, but are unable to offer any explanation of their difference from ours. We have prepared the salt in winter and in summer (when he found it difficult to work), by evaporation of cold solutions and by cooling hot solutions, and have always obtained crystals which slowly effloresced in the desiccator.

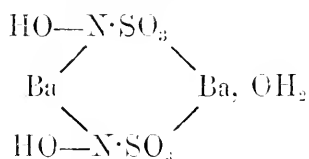
*Dibarium oxyamidosulphonate*, prepared by Fremy and by us, is a crystalline, alkaline, nearly insoluble salt. It dissolves in hydrochloric acid, and then shows by the odour evolved, the presence of sulphite, from a trace only to even much, as an impurity. The only analytical datum given by Fremy is that the salt is formed from one equivalent of acid and two equivalents of baryta. We have analysed it and found for it a composition agreeing with the formula given by Fremy less the  $\text{H}_2$  by which his formulae generally exceed those now adopted.

In this analysis and that of the following salt we slightly modified the method of hydrolysing, so as to get uniform and higher numbers for the hydroxyamine. The modification consisted in heating for some time with hydrochloric acid only to  $100^\circ$ , before raising the temperature to  $130^\circ$ . Simple hydroxyammonium sulphate may be rapidly heated with acid to  $130^\circ$  or even higher without getting low results, from which it would appear that at the moment of its formation at  $130^\circ$  from its sulphonic derivative, hy-

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\* Slight loss of potassium sulphate during cooling known to have occurred.

droxyamine is less stable than when already formed. The constitution of the dibarium salt is expressed by the formula—



	Calculated.	Found.
Barium	53.31	53.13
Sulphur	12.45	12.41
Oximidogen, HOX.	12.06	12.02

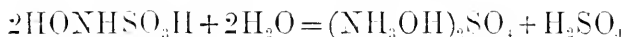
*Barium oxyamidodisulphonate*, prepared by us, in solution first, as already described in this paper, by adding just enough sulphuric acid to the dibarium salt to remove half its barium. The neutral liquor thus obtained yields by evaporation over sulphuric acid crystals of the salt. It is a very soluble salt and forms small hard brilliant square tabular crystals, intermixed with minute square prisms. When long kept it decomposes. Its crystals contain water. Heated nearly to 100°, it suddenly and violently decomposes into gases and barium sulphate.

In analysing it the barium was determined in one case by igniting with sulphuric acid (*a*): in two cases the salt was slowly heated with dry sodium carbonate, whereby oxygen was absorbed from the air, after which the heat was raised to fusion of the mixture, and the barium and sulphur both determined (*b*); while in another case, the salt was hydrolysed by heating with hydrochloric acid, the separated barium sulphate (representing all the barium and half the sulphur of the salt) weighed, the other half of the sulphuric acid precipitated with barium chloride, and lastly the hydroxyamine titrated with iodine (*c*). The results were the following—

	$(\text{HONHSO}_3)_2\text{Ba}, \text{OH}_2$	<i>a.</i>	<i>b.</i>	<i>b.</i>	<i>c.</i>
Barium	36.15	36.17	36.27	35.88	35.53
Sulphur	16.88		16.84	16.65	16.49
Oxyamidogen,	16.88				16.50

### The hydrolysis of oxyamidosulphonic acid.

Although oxyamidosulphonic acid possesses relative stability, the fact that its solution does decompose was fully noticed by Fremy. Raschig has found that the decomposition proceeds sharply and, in presence of hot acid, rapidly, according to the equation—



and with this important finding we fully agree from experience, and to it have nothing to add. Fremy stated that when boiled with water the acid decomposes wholly into acid-ammonium sulphate and oxygen or hydrogen-peroxide. His finding ammonia and oxygen (or any gas) cannot be explained. He appears to have tested for hydrogen-peroxide by adding manganese binoxide, which would account for his finding it, since an effervescence of nitrous oxide could easily pass for one of oxygen.

Claus expressed his hesitation to accept Fremy's equation (modified)— $2\text{HONH}(\text{SO}_3\text{H}) + 2\text{H}_2\text{O} = 2(\text{NH}_4)\text{HSO}_4 + \text{O}_2$ , as quantitative, but at the same time admitted that he had also obtained (besides sulphuric acid) ammonia and oxygen (or nitrous oxide.) Raschig has got other results, as already stated, and in these both ammonia and either oxygen or nitrous oxide are absent. These inexplicable differences have their parallel in what is contained in the next section of this paper, only there the differences announced are between ourselves and the other workers.

In presence of potassium-acid-carbonate oxyamidodisulphonates react with iodine solution like a hydroxyamine salt, only very much more slowly, so that without previous hydrolysis their amount can be titrated in this way though only with difficulty.

### **Decomposition of oxyamidodisulphonates by alkaline bases.**

The decomposition of oxyamidodisulphonates by a solution of potassium hydroxide had apparently been fairly well worked out when we came to give attention to it. Fremy had observed that when heated with excess of this reagent the potassium salt disengaged ammonia, as well as oxygen of which, as he says, he had established the absolute purity by analysis. Hence it seemed that oxyamidodisulphonates undergo the same decomposition when heated with alkali as when heated with acid.

Lossen had just discovered hydroxyamine when work upon the sulphazotised bodies was taken up by Claus, and this circumstance led the latter to see in the reaction between potassium hydroxide and Fremy's sulphazidate, as observed by Fremy and by himself, most convincing evidence that the salt is constituted as a sulphonic derivative of hydroxyamine, and decomposes with alkali into this base and potassium sulphate. He did not, he admits, succeed indeed in isolating the hydroxyamine or any of its salts, but he found all the sulphur of the sulphazidate converted into sulphate, and just the other bodies and in just the proportions which Lossen had found hydroxyamine to yield when heated with alkali, namely, ammonia equivalent to between a third and a half of the total nitrogen, and gases which neither extinguished nor rekindled a glowing match, which were, therefore, not the pure oxygen of Fremy's finding, and which might well be nitrogen mixed with nitrous oxide, as required

on the supposition made. Added to this was the fact of the reducing action which the alkaline mixture exerted upon copper and silver, and the proof seemed complete.

Raschig, in his recent paper, went further in the matter than Claus and, with or without experimenting we cannot decide from his words, concluded that an (unheated) alkaline solution of oxyamidosulphonic acid is actually a solution of free hydroxylamine in the quantity calculated from the amount of the acid taken, and therefore just such a solution of hydroxylamine as is used and wanted for preparing aldoximes and acetoximes.

Now with the exception of nitrous oxide being given off, and that of reduction of copper and silver salts—an action to be treated of in the following section of this paper, none of the observations of these chemists have we been able to confirm. This decomposition of oxyamidosulphonates by alkali is of another and still more interesting character than Claus and Raschig conceived it to be. That the oxyamidosulphonates are hydroxylamine derivatives, which hydrolyse in *acid* solutions into hydroxylamine and sulphate, is indeed certain, as ascertained by Raschig. But, nevertheless, in *alkaline* solution they give neither sulphate nor hydroxylamine, nor the decomposition-products of hydroxylamine.

Oxyamidosulphonates decompose with potassium hydroxide, and similar reagents, exclusively into sulphite and hyponitrite, and the decomposition-products of a hyponitrite. No ammonia and, so far as we could judge, no sulphate and no nitrogen—or if any only unimportant quantities of nitrogen and sulphate—are formed. The difficulty of keeping a sulphite solution for days free from sulphate, and of detecting small amounts of nitrogen in presence of nitrous oxide are well-known facts sufficiently explaining any uncertainty in

our assertions. The total absence of ammonia peremptorily forbids any admission of the generation of hydroxyamine.

Cold dilute alkali or alkaline-earth hydroxide suffices to partly effect the change under consideration. Consequently every attempt to form dipotassium or sodium oxyamidosulphonate corresponding with the dibarium salt has failed in our hands because of this resolution of the salt into simpler ones on adding alkali. Also for the same reason Fremy's dibarium salt, described in this paper, although an almost insoluble salt, cannot, we find, be prepared quite free from sulphite, and when kept for any considerable time becomes charged with it and with traces of hyponitrite.

To effect the complete or nearly complete conversion of these salts into sulphite and hyponitrite they may be either left for days in the cold with the very strongest potassium-hydroxide solution, or be heated to boiling for a short time with strong alkali. In both cases effervescence occurs, due to the decomposition of hyponitrite. The gas is not the feeble supporter of combustion met with by Claus, but so far behaves as oxygen, as Fremy had observed. Only it is not oxygen but nitrous oxide, soluble in water. The highly alkaline liquor when acidified gives abundance of sulphur dioxide, and when only neutralised gives with barium chloride a precipitate which might of course be taken for sulphate by a mind prepossessed as Claus's almost admittedly was, and which does, as is well-known, rapidly change into sulphate on the filter. When partially or fully neutralised with acetic acid the solution gives on treatment with sufficient silver nitrate much silver hyponitrite together with a very little reduced silver owing to the never quite complete destruction of the sulphonie salt. At first the silver nitrate is consumed in forming potassium-silver sulphite, and this consumption can be avoided if desired, either by using the barium salt instead of the potassium salt,

or by adding barium hydroxide, and then filtering off barium sulphite before adding silver.

This decomposition actually furnishes much the most productive method of preparing hyponitrite yet discovered. The following are the results of some trials we have made, the silver hyponitrite having been purified by the authors' method (*J. Ch. Soc.*, **45**, 81) of dissolution in nitric acid and reprecipitation with sodium carbonate. Generally the silver hyponitrite was directly weighed, but in one or two cases it was converted to chloride for weighing :

Digestion of 0.5772 gram of crystals of potassium oxyamidosulphonate for twenty-four hours with a saturated solution of potassium hydroxide and a bit undissolved, still contained a very small quantity of the sulphonic salt undecomposed. But the yield of hyponitrite came up in this case to 76 % of the full amount ;

Boiling 0.9370 gram of crystals with concentrated potassium hydroxide for a short time was attended with copious effervescence of nitrous oxide, and left still a little undecomposed salt, but the yield of hyponitrite still reached 30 % of the equivalent of the salt taken.

Merely to prepare hyponitrite from nitrite in this way there is no necessity of getting first a pure oxyamidosulphonate, a well-prepared solution of either alkali-salt sufficiently concentrated is quite serviceable if treated with solid potassium hydroxide. Working in this way we found —

0.4545 gram sodium nitrite,\* the final treatment of which, after conversion to the sulphonic salt, was in the cold with the most concentrated potash for twenty-four hours, gave hyponitrite

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\* Measured off for analysis as oxyamidosulphonate solution produced from a large quantity of nitrite worked upon.



amounting to 40 % of the full yield, had all the nitrite been utilised ;

0.5833 gram sodium nitrite,\* by final cold treatment for twelve days with the potash, when still a little undecomposed salt remained, gave a yield of hyponitrite equivalent to  $33\frac{1}{2}$  % of the nitrite;

0.4171 gram sodium nitrite\* by final first cold treatment for twenty-one hours and then at  $100^{\circ}$  for a quarter-hour yielded hyponitrite amounting to  $49\frac{3}{4}$  % of the calculated quantity.

But in order to get such results as these, referred to the nitrite taken, our modification of the process for getting the oximidosulphonate must be followed, an account of which we reserve for the paper on these salts. Here we need only mention that we can get at least 85 % of the calculated quantity of oximidosulphonate from nitrite, a proportion far higher than previously got by Raschig, the only quantitative worker.

In consequence of the decomposition of much of the potassium hyponitrite into hydroxide and nitrous oxide, the measure of the hyponitrite does not of itself serve to prove that the formation of this salt is the only decomposition of the oxyamidossulphonate. But it does make this deduction highly probable when taken along with the occurrence of so much nitrous oxide and sulphite, and with no ammonia, nitrogen, or sulphate. The determination of sulphite is, however, what seems sufficient of itself to prove the singleness of the decomposition, although here too any very close approach to the calculated amount cannot be expected, considering the ready oxidisability of sulphites to sulphates, and that not quite all the sulphonate is ever decomposed. In consequence of the presence of hyponitrite and its reaction with iodine, a volumetric estimation of the sulphite with iodine was not possible. We therefore availed ourselves of the

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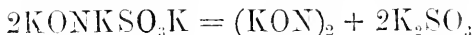
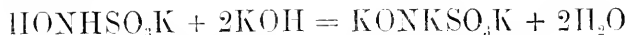
\* See not on p. 221.

reaction of sulphurous acid with stannous chloride for its estimation. Stannous chloride has no action upon hydroxyamine (Divers and Haga, *J. Ch. Soc.* **47**, 624), and none upon oxyamidosulphonic acid.

Our procedure was to put in a pressure-bottle the diluted solution of the salt decomposed by alkali and neutralised, mix it with excess of stannous chloride, and almost fill the bottle with water. Some arsenious oxide was also added in order to fix all hydrogen sulphide in presence of the necessary excess of hot acid, which was, however, not so concentrated as to lead to reduction of arsenic by the tin-solution. The tightly closed bottle was kept in nearly boiling water for an hour, and then left to cool. The washed precipitate of stannous sulphide was heated with hydrochloric acid and potassium chlorate until all sulphur had oxidised, and the solution evaporated to dryness, and again evaporated with hydrochloric acid to dryness. Finally, after removing the tin by hydrogen sulphide, the sulphuric acid in the filtrate was estimated as barium salt. In this way, from 0.7470 gram of salt, which by long keeping had slightly hydrolysed, we got sulphur equivalent to 88.63 per cent. of all in the original sulphonic salt. Another sample, freshly crystallised, in fine plates, was boiled with the potassium hydroxide, entirely out of contact with air, by keeping it in an atmosphere of hydrogen. Thus treated, the product, with the tube containing it, was dropped into the bottle of stannous chloride. In this case, 0.2007 gram gave 89 % (89.05) of the sulphur as sulphite. These results render it clear that sulphite and therefore hyponitrite are the two and only primary products of the change.

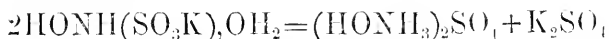
The reaction by which hyponitrite and sulphite are formed consists probably in the substitution of the hydrogen of the oxyamido radical by potassium, and then of self-decomposition of the potassium compound. There is no hydrolysis or saponification, simply dis-

sociation or chemical fission —



Raschig has observed a closely similar decomposition of Fremy's potassium sulphazite by strong potash into sulphite and nitrite.

We would gladly account for the differences between the results found by the other chemists and our own, but we can do little in this direction. We have to face the fact that Claus's work was quantitative. The only suggestion we can offer is that Fremy and Claus's originally pure preparations were not treated with alkali until they had been kept long enough to undergo their usual decomposition (fully in Claus's case) —



into hydroxyamine and sulphate. Such a mixture would behave just as they found. As for oxygen, Fremy must have mistaken nitrous oxide for it, and in making this supposition we have evidently the support of Claus and Raschig. Lastly, as for Claus's nitrous oxide diluted with nitrogen, dilution with air and steam may perhaps have been the cause of his not having got such a gas as Fremy and we ourselves got.

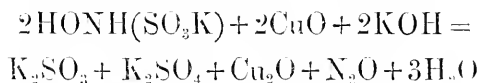
Oxyamidosulphonates evaporated to dryness on a water-bath with either potassium or sodium carbonate evolves carbon dioxide during the last stages of the evaporation, and yields much sulphite. No hyponitrite can remain undecomposed in such circumstances. Even a solution of the oxyamidosulphonate left in the cold for a day with the carbonate shows evidence of the presence of a little sulphite.

Repeated evaporations with potassium acetate leave an alkaline mixture containing a minute quantity of sulphite.

### Oxidation of oxyamidosulphonates by basic reagents.

Fremy observed that manganese dioxide dissolved as manganous salt in oxyamidosulphonic acid with effervescence of oxygen. Also that the same reagent caused a lively effervescence in a solution of the potassium salt. In these observations he was right save in mistaking nitrous oxide for oxygen. Finally, he found that the potassium salt immediately reduces salts of silver, copper, and gold. We must except copper from this statement, when alkali is absent. Claus found that in the presence of potassium hydroxide the potassium salt reduces salts of copper and silver in the cold, just like hydroxyamine, as we have already had occasion to mention, but he made only qualitative experiments. Raschig, who holds that alkali converts oxyamidosulphonates wholly into their equivalent of hydroxyamine, records no experimental determination of this point, though he quantitatively estimated the hydroxyamine produced by the action of an acid.

The reaction which takes place in our hands is the conversion of the oxyamidosulphonate into sulphite and sulphate and the reduction of a quantity of metal-oxide equivalent to the oxidation of the oxyamide residue, and not of hydroxyamine supposed to be produced. That is to say, the cuprous oxide obtained is half what it would be were hydroxyamine first formed as believed by Claus and Raschig. The equation, therefore, will stand thus —



which shows the potassium hydroxide taking the two sulphonic residues to form sulphite, sulphate,\* and water, and the copper-oxide oxidising to water the one hydrogen of each of the oxyamido residues, thus leaving hyponitrous acid to resolve itself finally into nitrous

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\* Hyposulphate was searched for, and could not be found.

oxide and water. After the reduction, addition of hydrochloric acid liberates much sulphur dioxide.

The reaction does not quite complete itself, ceasing when the solutions become very dilute. Thus, if to a solution of one gram of the oxyamidosulphonate in a liter, only a few drops of a dilute solution of copper sulphate and then of potassium hydroxide are added, the mixture shows a permanent blue opalescence, but deposits no cuprous hydroxide, even when preserved for hours in a closed vessel. This observation may serve to show that although, when very dilute, alkali does not produce much sulphite and hyponitrite, this is not because hydroxyamine and sulphate are produced instead, for if such were the case the hydroxyamine would then act upon the cupric hydroxide.

The fact that the alkaline solution contains not hydroxyamine but a sulphonic derivative of it, which gives sulphite in its reactions with reducible bodies, and that it has only half the action of its equivalent of hydroxyamine, are serious, if not fatal, objections to resorting to it as a reagent on organic compounds, as Raschig has suggested may economically be done. This chemist, notwithstanding that he has pointed out (his memoir, p. 182) that the reason that oximidosulphonates do not possess any of the reducing power of hydroxyamine, is that in them the two active hydrogens of hydroxyamine are replaced by sulphonic radicals, and that oxyamidosulphonates by retaining still one of these hydrogens remain as equally easily reducible as hydroxyamine itself, has yet failed to see that, his contention being well-founded, it will be the oxyamidosulphonate and not hydroxyamine which exerts the reducing power of its alkaline solution. That it is so, is shown by the fact, determined by us, that in the absence of reducible agents, alkalis to a small extent do not decompose oxyamidosulphonates and for the rest change

them into sulphite and hyponitrite, neither of which gives a cuprous precipitate in presence of alkalis.

- We have yet to supply particulars of our quantitative work. The amount of sulphite produced was imperfectly estimated unavoidably, partly because of the great oxidisability of the very dilute alkaline sulphite by air, and partly because of the always incomplete decomposition of the oxyamidosulphonate. To measure it, the mother-liquor of the copper precipitate was run into excess of half-decinormal iodine-solution (mixed with acid enough to more than neutralise the alkali in the mother-liquor), and the unconsumed iodine titrated with sodium thiosulphate. All the water used was previously freed from air by boiling. Of the salt, 1.0967 grams, treated with copper sulphate and potassium hydroxide, gave in this way 40 % of the sulphur of the salt as sulphite, and that was our best result. Theory, as given by us, indicates 50 %, while on the other view there should be none at all. Other portions of the mother-liquor of the copper precipitate were acidified for hydrolysis of any remaining sulphonate, and concentrated by evaporation. One of these then gave quite a distinct further reduction with the copper mixture, due to hydroxyamine, while another measured portion showed on titration with iodine in presence of potassium-acid-carbonate the presence of hydroxyamine, equivalent however to only one-twelfth of the whole salt.

To measure the amount of copper reduced we added to 0.2913 gram of the salt (already very slightly hydrolysed, by keeping), dissolved in water, a sort of Fehling's solution, much stronger than usual and with much less alkali in it, in slight excess, heated to boiling to collect the cuprous oxide, filtered, rapidly washed, and weighed the reduced oxide as black oxide. We thus obtained cupric oxide equal to 48 % of the weight of the salt instead of 47 %.

calculated from our equation. On the other theory, twice as much should have been got.

We then applied the stannous-chloride process, avoiding all exposure to air by treating the salt in the pressure-bottle to be afterwards used in the analysis, with the alkali and copper salt in a current of hydrogen. To the resulting mixture, and without removal of the cuprous oxide, we added, still in an atmosphere of hydrogen, the necessary stannous-chloride and acid. Only then and for a moment was the bottle opened in order to replace the cork and gas tubes by the stopper of the bottle. Heated, as before, 0.4298 gram of freshly crystallised salt gave 41 % (43.93) of the sulphur as sulphite, a result confirmatory of our theory, and better than that (40 %) got by iodine-titration.

It thus appears clear that the sulphite formed when the oxyamidodisulphonate is oxidised by cupric oxide is half what is produced when the salt is decomposed by alkali alone. That only nine-tenths of the reckoned sulphite is obtained in both cases is partly if not entirely due to two causes. One of these is that, as already pointed out, in each mode of decomposition, a little oxyamidodisulphonate (or a body like it) is always left at the end of the reaction. The other and main one is that the tin reaction is incomplete, for working upon sulphite of a known degree of purity we have got only 91 and again 93  $\frac{1}{2}$  % of the sulphite indicated.

In alkaline solutions, silver and mercuric hydroxides act quite similarly to cupric hydroxide, qualitatively at least, and yield much sulphite.

### **Constitution of hyponitrites, as revealed by the decomposition of oxyamidodisulphonates.**

The decomposition of oxyamidodisulphonates into sulphite and hyponitrite sets at rest any doubt as to the constitution of hyponitrites.

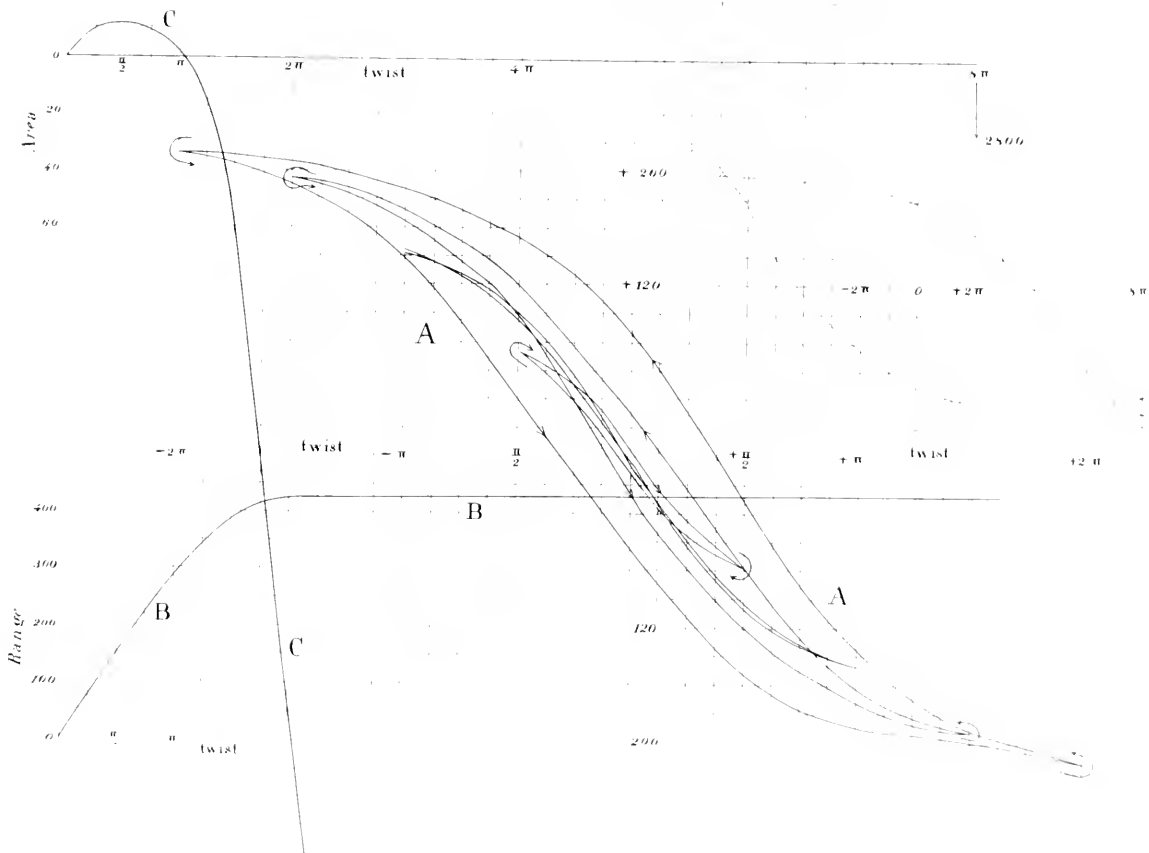
For coming in this case directly from a substituted hydroxylamine a hyponitrite must have its oxygen between the nitrogen and metal.

Berthelot and Maquenne have recently published papers (*Compt. rend.* **108**, 1286, 1305) containing analyses of calcium and strontium hyponitrites. These analyses, as they point out, establish the accuracy of the empirical formula given by one of us (Divers) to hyponitrous acid, upon which doubt had been cast by the previous work upon the silver salt by Berthelot himself and Ogier (*Compt. rend.* **96**, 30, 84). To this salt the latter chemists gave the formula  $\text{Ag}_2\text{N}_2\text{O}_2$ , the correctness of which was afterwards contested by us (*J. Ch. Soc.* **45**, 78). Berthelot now admits this salt to be not obtainable in a pure state, thus also confirming us, as against Zorn, van der Plaats, and Menke, all of whom claimed to have got it pure without difficulty. Zorn's opinion that the molecule of the acid contains two atoms of each of its elements, already generally accepted, is now endorsed by Berthelot and Maquenne. Lastly, Maquenne is disposed to deny that nitrous oxide can be the anhydride of hyponitrous acid, even to the extent that carbon monoxide is the anhydride of formic acid, but on grounds which to us seem quite insufficient. Even the facts recorded in this paper can leave hardly a doubt that it is so. The formula of hyponitrous acid may now confidently be written as  $\text{HON}_2\text{OH}$  or  $(\text{NOH})_2$ , that is, the acid is hydroximidogen, of which  $\text{NOH}$  is the radical.



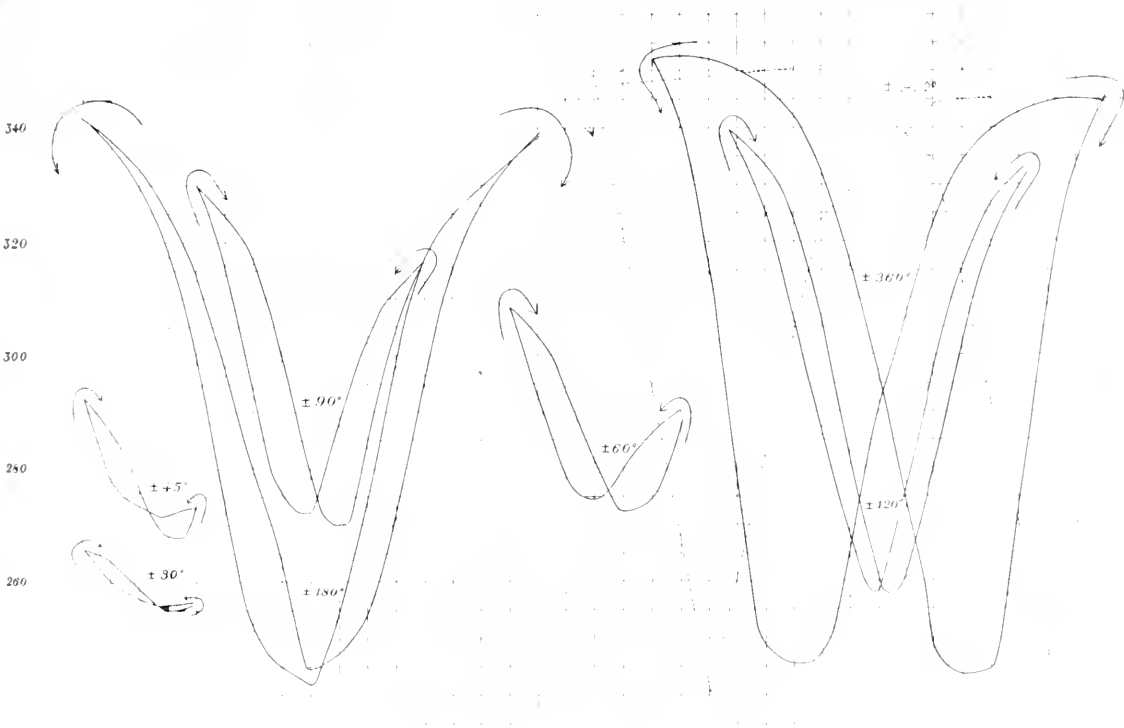




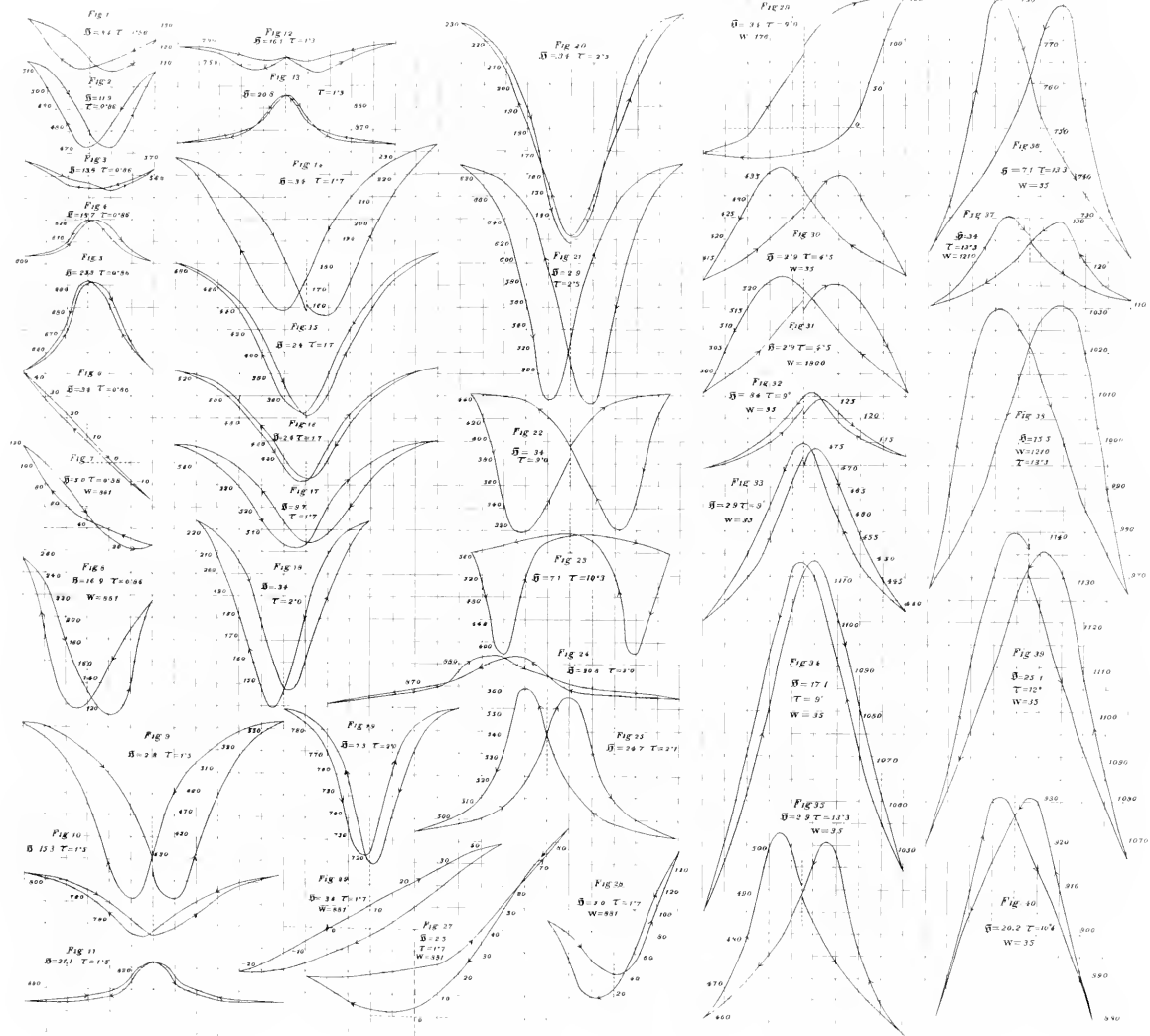




*Magnetic Lag in twisted Nickel longitudinally magnetised.*









# On a Condensation Product of Acetone and Aldehydammonia,

by

Mitsuru Kuhara, Ph. D.

Some time ago A. Hantzsch<sup>1</sup> obtained, by the condensation of acetone and aldehydammonia, a complex mixture of basic substances boiling between 150° and 360°, from which he could only separate collidine which was formed as a direct condensation product of aldehydammonia. I have, likewise, attempted to carry on for the last four years the same line of investigation, in a somewhat different manner and have succeeded in separating a basic substance besides collidine from that complex mixture. The results of the author's experiments have already been communicated to the Tokyo Chemical Society in June, 1888. In September of the same year E. Durkopp<sup>2</sup> published the results of his researches on the same subject, in which he gives an account of a basic substance which was formed by the condensation of acetone and aldehydammonia. His compound is, however, probably isomeric with that obtained by the present author, as both compounds are similar in some respects and have the same molecular formula.

In the author's experiments, a mixture of 1500 grams of acetone and 750 grams of aldehydammonia was continually heated at 120°-130° for 25 hours in a cast iron digester over an oil bath. When the digester was opened, its contents were found to be a dark brown

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1. Ber. d. deut. chem. Gesell. **14**, 1637.

2. " " " " " **21**, 2713.



liquid of thick oily consistency, with a strong ammoniacal odour. The whole was transferred to a retort and subjected to distillation over a water bath, by which means a greater part of the unchanged acetone was removed. The remainder of the liquid was then distilled over an oil bath to get rid of the remaining traces of acetone and the water formed in the reaction, until the temperature reached  $120^{\circ}$ . The retort was then heated above the last temperature over a direct flame, but a very small quantity of an oily liquid distilled over until the temperature attained  $170^{\circ}$ . From  $170^{\circ}$  to  $230^{\circ}$ , however, a large quantity of a pale yellow oil, and above  $230^{\circ}$  some thick syrupy liquid distilled over. The residue in the retort was of a dark brown resinous matter.

On subjecting the liquid boiling between  $170^{\circ}$  and  $230^{\circ}$  to fractional distillation, an amber-coloured oil which boils at  $173^{\circ}$ - $176^{\circ}$  was separated. It soon turns brown in contact with air, even slightly in the process of distillation. The oil has a strong stupifying odour somewhat resembling that of conine. When inhaled, it causes a headache. It is poisonous; for a drop of it will instantly kill a large frog. It gives white fumes with hydrochloric acid, and combines with common mineral acids with the evolution of heat. It is slightly soluble in cold water, but on warming, it precipitates.

As it soon changes in contact with air, it was thought best to convert into a platinum double salt, which is more stable. To do this the oil was dissolved in dilute hydrochloric acid, and on adding platinum chloride to the solution, a double salt was precipitated as a yellow crystalline powder. The precipitate was again dissolved in hot water in which it is moderately soluble, and from the solution on cooling, large reddish-yellow feather-shaped crystals of the double salt were deposited. On repeating several times the crystallization of the double salt from the hot water, the pure salt—for such it was judged

to be from its appearance—was obtained. The crystals, after being dried over sulphuric acid, were analysed.

I. 0.3751 gram of the double salt on combustion gave 0.1502 gram  $\text{H}_2\text{O}$  and 0.4114 gram  $\text{CO}_2$ .

II. 0.3755 gram of the double salt gave 0.1419 gram  $\text{H}_2\text{O}$  and 0.4245 gram  $\text{CO}_2$ .

III. 0.4451 gram of the double salt gave 0.1778 gram  $\text{H}_2\text{O}$  and 0.4636 gram  $\text{CO}_2$ .

IV. 0.3364 gram of the double salt gave 0.149 gram  $\text{H}_2\text{O}$  and 0.3188 gram  $\text{CO}_2$ .

V. At first the double salt was reduced by sodium amalgam and then the chlorine estimated in the usual manner; upon which 0.3248 gram of the double salt gave 0.4243 gram  $\text{AgCl}$ .

VI. 0.295 gram of the double salt, when burnt with soda lime, gave 0.212 gram  $2\text{NH}_4\text{Cl}.\text{PtCl}_4$ .

The double salt, on ignition, gave the following amount of platinum :

I.	0.1974	gram	the	double	salt	gave	0.0591	gram	Pt.
II.	0.3756	..	..	..	..	..	0.4137	..	..
III.	0.2244	..	..	..	..	..	0.0680	..	..
IV.	0.2569	..	..	..	..	..	0.0769	..	..
V.	0.2020	..	..	..	..	..	0.0611	..	..
	I.	II.	III.	IV.	V.	VI.			
Carbon ..	...30.07	28.39	30.81	28.27	—	—			
Hydrogen ...	4.44	4.48	4.19	4.91	—	—			
Nitrogen ...	—	—	—	—	4.51	—			
Chlorine ...	—	—	—	—	—	32.24			
	I.	II.	III.	IV.	V.				
Platinum ...	...30.06	30.27	29.76	29.76	30.24				

	Mean (found).				Calculated as $(C_8H_{13}N)_2H_2Cr_2O_7$ .			
Carbon ... ..	...	...	...	29.38...	...	...	...	29.19
Hydrogen ... ..	...	...	...	4.50...	...	...	...	4.25
Nitrogen ... ..	...	...	...	4.51...	...	...	...	4.25
Chlorine ... ..	...	...	...	32.24...	...	...	...	32.38
Platinum... ..	...	...	...	30.00...	...	...	...	29.93
				<u>100.63</u>				<u>100.00</u>

*The Hydrobichromate*,  $(C_8H_{13}N)_2H_2Cr_2O_7$ .—To the base dissolved in dilute sulphuric acid, some crystals of potassium bichromate were added and the mixture gently heated. On cooling the solution, the hydrobichromate crystallized out in large brilliant yellow prismatic plates, and upon recrystallization it was soon obtained pure. It is sparingly soluble in cold, but easily in hot water. When heated, it deflagrates and leaves a green oxide  $Cr_2O_3$ . The crystals of the hydrobichromate, after being dried over sulphuric acid, were analysed :

- I. 0.3557 gram the salt gave, on combustion, 0.1853 gram  $H_2O$  and 0.5491 gram  $CO_2$ .
- II. 0.2504 gram the salt, when ignited, gave 0.0831 gram  $Cr_2O_3$ .
- III. 0.1886    "    "    "    "    "    "    "    "    0.062    "    "

	Found.			Calculated as $(C_8H_{13}N)_2H_2Cr_2O_7$ .			
	I.	II.	III.	...	...	...	...
Carbon	41.88	—	—	...	...	...	41.31
Hydrogen	5.79	—	—	...	...	...	6.02
Nitrogen	—	—	—	...	...	...	6.02
Chromium	—	22.36	22.54...	...	...	...	22.54
Oxygen	—	—	—	...	...	...	24.09

*The Mercury Double Chloride*,  $C_8H_{13}N.HCl.2HgCl_2 + H_2O$ .—On adding the solution of mercuric chloride to the aqueous solution of the hydrochloride of the base, fine hairy white crystals separated out in

a few minutes, and upon recrystallization from a solution in hot water, the pure double salt, for so it was judged to be from its appearance, was obtained in large brilliant scaly plates. The salt melts at  $148^{\circ}$ - $149^{\circ}$ . It partially volatilizes at above  $100^{\circ}$ . It seems to contain one molecule of the water of crystallization, but on account of its volatility its amount cannot be accurately determined by the usual method. The crystals of the double salt, after being dried over calcium chloride, were analysed :

(I.) 0.3957 gram the double salt gave 0.3941 gram AgCl.

(II.) 0.3645 .. .. . 0.2353 .. HgS.

	Found.		Calculated as	
	I.	II.	$C_8H_{13}N.HCl.2HgCl_2 + H_2O.$	
Chlorine...	24.64	...	...	24.66
Mercury...	...	55.63	...	55.59
Water ...	...	...	...	2.50

The crystals of the double salt, finely pulverized, were heated over an air bath at  $130^{\circ}$  for some time, by which the powder became compact, having apparently lost its water of crystallization through partial volatilization. The salt was then analysed.

0.3887 gram the anhydrous salt gave 0.2593 gram HgS.

	Found.		Calculated as	
			$C_8H_{13}N.HCl.2HgCl_2.$	
Mercury...	...	57.83	...	57.2

On comparing this analytical result with that given in the preceding analysis, we may infer that the salt contained one molecule of water.

*The Gold Double Salt,  $C_8H_{13}N.HCl.AuCl_3$ .*—This was prepared by adding an alcoholic solution of gold chloride to an aqueous solution of the hydrochloride of the base. On driving off the alcohol from the solution, the double chloride separated out as a crystalline precipitate, which consisted of microscopic yellow needles. It was

redissolved in hot water and repeatedly recrystallized. It melts under hot water to a sticky oily mass and solidifies again on cooling. The salt, dried over calcium chloride, was analysed :

0.3386 gram the salt gave 0.1452 gram Au.

	Found.	Calculated as $C_8H_{13}N.HCl.AuCl_3$ .
Gold...	...42.88...	...42.51

*The Hydrochloride.*  $C_8H_{13}N.HCl$ .—On mixing concentrated hydrochloric acid and the base together, they combined energetically with the evolution of heat, and the mixture solidified. The whole mass was then dissolved in alcohol, and on concentrating the solution nearly to dryness the hydrochloride crystallized out, in an impure state, in the form of long needles. The impure salt thus obtained was purified by dissolving it in the smallest possible quantity of alcohol, and then adding ether to the alcoholic solution, by which means the hydrochloride was precipitated in fine colourless needles, as it is insoluble in ether. It is exceedingly deliquescent in air. The crystals seem to decompose under a desiccator, as they soon lose their transparency, probably giving off a part of hydrochloric acid. The crystals, dried over sulphuric acid under a desiccator, were analysed :

I. 0.1540 gram the salt gave 0.1300 gram  $AgCl$ .

II. 0.2112    „    „    „    .. 0.1819    „    ..

III. 0.1500    „    „    „    .. 0.1276    „    ..

	Found.			Calculated as $C_8H_{13}N.HCl$ .
	I.	II.	III.	
Chlorine...	...20.88	21.25	21.32...	...22.25

The low percentage of chlorine, in the above analysis, may possibly be due to the decomposition of the salt during desiccation.

*The Hydrobromide.*  $C_8H_{13}N.HBr$ .—On adding bromine to the base dissolved in ether containing some alcohol, the hydrobromide

separated out in colourless transparent prismatic needles. The salt, dried over calcium chloride, was analysed :

0.2946 gram the salt gave 0.27 gram AgBr.

	Found.	Calculated as $C_8H_{13}N.HBr$ .
Bromine...	...39.13...	...39.21

*The Acetyl Compound*,  $C_8H_{12}N(CH_3CO)$ . This was prepared in the usual way, by dissolving the base in anhydrous ether and adding acetyl chloride to it. The hydrochloride of the acetyl compound thus precipitated was purified by repeated recrystallization from the mixture of alcohol and ether. It crystallizes in fine needles, in appearance very much like the hydrochloride of the base. It is very deliquescent. The free acetyl compound separates out as an oil, on adding caustic potash to its hydrochloride. The salt, dried over calcium chloride, was analysed.

0.2649 gram the hydrochloride of the acetyl compound gave 0.1906 gram AgCl.

	Found.	Calculated as $C_8H_{12}N(CH_3CO)HCl$ .
Chlorine...	...17.79...	...17.61

*The Nitroso-compound*,  $C_8H_{12}N.NO$ .—On adding pieces of solid potassium nitrite gradually to the aqueous solution of the hydrochloride of the base, a large quantity of a thick brown oily substance separated. It was extracted with ether, and shaken with water, and again extracted with ether. After repeating the same process of washing several times, the oil, dried over calcium chloride, was once distilled. It is a pale yellow oil, having the characteristic odour of nitrosamine. It gives the well-known Liebermann's nitroso-reaction ; consequently the base itself is a secondary amine.

The solution left after separating the nitroso-compound, was treated with caustic potash, by which a small quantity of an oil was

precipitated. The latter was then changed into an hydrochloride, and consequently into a double salt, with mercuric chloride. The double salt thus prepared was found to be identical with the double salt of the original base, agreeing in its crystalline form, melting point, and analytical results. The double salt, dried over calcium chloride, was analysed, and the results were as follow :

I.	0.2396	gram	the double salt	gave	0.2353	gram	AgCl.
II.	0.2000	„	„	„	„	0.1958	„
III.	0.3165	„	„	„	„	0.2037	„ HgS.
IV.	0.3378	„	„	„	„	0.2200	„

	Found.				Calculated as	
	I.	II.	III.	IV.	$C_9H_{13}N.HCl.2HgCl_2 + H_2O.$	
Chlorine...	...24.30	24.22	- -	—	...	...24.66
Mercury...	... —		55.47	55.50...	...	...55.59

It is evident, therefore, that a greater part of the base changed into a nitrosamine, and the oil separated from the solution with caustic potash was simply the base unchanged.

According to the results of analysis thus far, it is highly probable that the author's base has the formula  $C_9H_{13}N$  and differs in many respects from the base isolated by Durkopp,\* although they are isomeric.

### The Oxidation and Decomposition of the Base.

On heating 10 grams of the base freshly distilled, with the chromic acid mixture consisting of 20 grams of potassium bichromate and 20 grams of sulphuric acid diluted with its own volume of water, the mixture gradually became green with the evolution of  $CO_2$ . The

\* Durkopp's base is stated to change into collidine on treating it with  $KNO_3$ .—Ber. d. deut. chem. Gesel. **14**:2713.

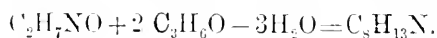
green solution thus formed was mixed with a large quantity of water and subjected to distillation; and in the distillate was found a considerable quantity of acetic acid and a little formic acid.

Next, the base was subjected to oxidation with a potassium permanganate solution containing 1 part of potassium permanganate to 8 parts of water. To the base a small portion of the solution was added from time to time, and it was heated over a water bath, and at each addition the solution was found immediately to decolorize, probably through the rapid breaking up of the base. The products of the oxidation were found to consist mainly of carbon dioxide and acetic acid.

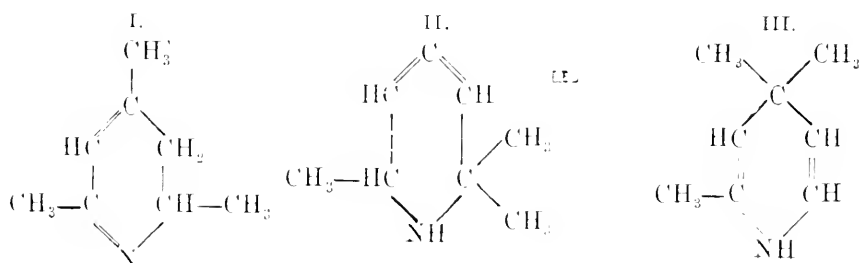
On distilling the base with dilute sulphuric acid, mesityl oxide was produced as one of the decomposition products, and on further continuing the distillation, it gradually became black, evolving  $\text{SO}_2$ .

### The Probable Constitution of the Base.

The condensation of aldehydammonia and acetone into the base  $\text{C}_8\text{H}_{13}\text{N}$  may be represented by the following equation:



Accepting the above equation as true, the formation of the base, by condensation may be possible in three ways, as may be seen in the following formulae:





The base would be identical, according to I, with Hantzsch's dihydrocollidine<sup>1</sup>, and according to II, with a dehydroderivative of Heintz's vinyl diacetoneamine<sup>2</sup>; but from the results of the experiments so far obtained, the author's base cannot be either one, or the other. It is, however, very probable that it has the formula III, considering the experimental results on the behaviour of the base given in the present paper. The details of its structure will be communicated in a future paper, as further investigations are being carried on.

1. *Annalen d. Chem.* **215**, 1.

2.     "     "     "     **178**, 326; **189**, 314; **191**, 122.

Sept. 1889, Chemical Laboratory,  
First Kōtō-Chu-Gakko.



# Capillary Attraction in Relation to Chemical Composition, on the Basis of R. Schiff's Data.

By K. Ikeda.

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Many physical properties of solid and liquid substances can be so measured and expressed that the quantity for a molecule is the sum of the quantities for its constituent atoms. The heat capacity of inorganic solids, the space occupied by liquids at their boiling points, refraction of light, and rotation of the plane of polarization under magnetic influence, are well known examples. The heat capacity of organic liquids under certain conditions and the magnetic behavior of the same probably belong to the list, and there is reason to believe that the heat of formation from dissociated atoms is also of the same description.

All these properties can be represented by the following simple formula,

$$F(\alpha, \beta, \gamma, \dots K) = ma + nb + pc + \dots$$

where  $K$  is the duly measured property, under consideration, of a compound whose chemical formula may be written  $A_m B_n C_p \dots$ ; while  $\alpha, \beta, \gamma, \dots$  are functions of other properties belonging to the substance, and  $a, b, c, \dots$  are special values for the atoms of the constituents  $A, B, C, \dots$ .

In all known instances  $\alpha, \beta, \gamma$ , &c, as well as  $F$ , are very simple functions.

It is the endeavor of the present paper to show that capillary attraction of organic liquids belongs to the above mentioned category of physical properties, and can be represented by the same general formula.

That there is a well defined relation between capillary constants of liquid substances and their molecular composition has been put beyond all doubt by the extensive and elaborate experimental investigations of R. Schiff. He has chosen boiling points as the temperature of physical comparability, and expressed the relation between capillary constants at these points and the chemical composition by the formula

$$N = \frac{\varepsilon^{a-bH}}{H},$$

in which  $N$  stands for the relative number of molecules raised in a capillary tube,  $H$  is the sum of the special values for the constituent atoms referred to hydrogen as unity,  $\varepsilon$  is the base of the Napierian logarithms, while  $a$  and  $b$  are constants. This equation accords fairly well with the experimental results; but it is hard to see why such a relation should exist between  $N$  and  $H$ , or rather the meaning of the latter term is very difficult to make out. The expression, indeed, claims no higher title than that of being strictly empirical; still it is better to use those terms only, to which some probable meaning, at least, can be assigned. The two formulæ about to be proposed are in no way superior to Schiff's as far as purely theoretical consideration goes, for they pretend to no theoretical ground whatsoever. Still they seem to be more rational inasmuch as the terms involved have some meaning, and besides agree better with the observed results, as will be shown later on. The new equations are of the same form as the general expression already given, and show the relation between capillary constants and molecular volumes in a very clear manner, although it is rather difficult to understand why they

should be of these particular forms. The formulæ may be written thus :

$$K = \frac{ma + nb + pc + \dots}{V^{\frac{1}{2}}} \dots (I_a)$$

or  $KV^{\frac{3}{2}} = ma + nb + pc + \dots (I_b)$

and  $K^{\frac{1}{2}}V^{1.125} = ma' + nb' + pc' + \dots (II).$

Here  $K$  stands for the capillary rise of a liquid multiplied by its specific gravity, both being taken at the boiling point.  $V$  is the molecular volume, or the molecular weight divided by the specific gravity ;  $a$ ,  $b$ ,  $c$ , &c and  $a'$ ,  $b'$ ,  $c'$ , &c are quantities having particular values for  $A$ ,  $B$ ,  $C$ , etc., and may be called atomic capillary constants.

If we assume the principle of molecular volumes to be rigorously true, then  $V$  may be expanded into  $ma + nb + pc + \dots$ , and  $K$  can be found out by mere calculation, provided the molecular constitution of the substance as well as  $a$ ,  $b$ ,  $c$ , &c or  $a'$ ,  $b'$ ,  $c'$ , &c and  $a$ ,  $b$ ,  $c$ , &c are known.

The data for the establishment of the above formulæ have, with only one exception been drawn from Schiff's publications. That exception is heptane for which the calculations have been made from Thorpe's determination. Schiff's investigations cover about one hundred and fifty compounds belonging to various types, and have been communicated to the scientific world in two papers, the first in Liebig's *Annalen* (**223**, 47-106), and the second in the *Gazetta* (**14**, 368-447). As the second periodical is not accessible to me, the information about his second communication is chiefly derived from the abstract published in the *Journal of the Chemical Society, London* (XLVIII, 717-721).\* \* On this account, the data

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\* There seems to be several misprints in this abstract, for instance nitriles are all spelt nitrites, the critical temperature  $T$  for the first seven compounds are all transplanted into the column for molecular volume, while the molecular volume of allylthiocarbimide is made equal to that of the phenyl compound. These considerations make me very unwilling to draw the data from this abstract for a misprint of a figure may vitiate the results of several calculations.

for the recalculation are very imperfect ; and as hunting for these in the various periodicals consumes more time than can well be spared, and moreover as the determination of the atomic capillary constant of an element requires the value of  $K$  to be known for many compounds of the same type containing the element under consideration, only about one hundred determinations have been submitted to recalculation. Still it is hoped that these will suffice for establishing the approximate validity of the new formula.

These one hundred and odd substances consist of compounds of carbon, hydrogen, oxygen, nitrogen, chlorine, bromine, iodine and sulphur. The atomic capillary constants have been calculated from the data, and from these  $KV^{\frac{2}{3}}$  &  $K^{\frac{1}{2}}V^{1.18}$ , as well as  $K$ , have been recalculated, with what agreement the following tables will show.

The atomic constants for the various elements ( $a$ ,  $b$ ,  $c$ , &c. in the formula) used in the calculation of the first table are as follows :

for carbon\* 600 in all cases

„ hydrogen 75 „ „ „

„ oxygen 170 in alcohols.

„ „ 450 when it is entirely combined with one or more carbon atoms.

„ chlorine 1100 when only one chlorine atom is united with a carbon atom.

„ „ 925 when more than two chlorine atoms are united with a carbon atom.

„ bromine 1500

„ iodine 2150

„ nitrogen 650 in amines, isocyanates, and nitro bodies.

„ „ 450 in nitriles and cyanates,

„ sulphur 1500

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\* The value for carbon is most probably higher than this in unsaturated compounds.

sulphur 1150 when two atoms of sulphur are combined with one atom of carbon.

When a polyvalent element is united with the benzene or pyridene ring the value of  $KV^{\frac{3}{2}}$  is increased by 300.

TABLE I.

Substance	$V$ Molecular Volume	$KV^{\frac{3}{2}}$	$ma + nb$ + $pc + \dots$	$K$ Observed	$K$ Calculated	Difference between $KV^{\frac{3}{2}}$ and $ma + nb$ per cent.	per centage Difference
Normal Hexane } $C_6H_{14}$	140.02	4530	4650	2.772	2.815	+120	+2.6
Normal Heptane } $C_7H_{16}$	162.56	5336	5400	2.575	2.606	+64	+1.2
Diisobutyl } $C_8H_{18}$	184.89	6059	6150	2.410	2.446	+91	+1.5
Diisomyl } $C_{10}H_{22}$	231.89	7718	7650	2.192	2.168	-68	-1.1
Amylene } $C_8H_{18}$	140.48	4564	4750	3.082	3.212	+186	+5.2
Octylene } $C_8H_{16}$	177.61	6074	6000	2.572	2.541	-74	-1.2
Diallyl } $C_6H_{10}$	126.10	4259	4350	3.008	3.072	+91	+2.1
Benzene } $C_6H_6$	96.47	4012	4050	4.254	4.295	+38	+1.0
Toluene } $C_7H_8$	118.25	4748	4800	3.692	3.733	+52	+1.1
Xylene (1:2) } $C_8H_{10}$	139.91	5551	5550	3.354	3.353	-1	0.0
„ (1:3) „	139.69	5544	5550	3.358	3.362	+6	+0.1
„ (1:4) „	140.21	5544	5550	3.340	3.343	+6	+0.1
Ethyl- benzene } „	138.96	5602	5550	3.420	3.388	-52	-1.0
Propyl- benzene } $C_9H_{12}$	161.82	6427	6300	3.122	3.061	-127	-2.0
Ethyl- toluene } „	161.95	6373	6300	3.092	3.057	-73	-1.1
Mesitylene „	162.41	6234	6300	3.012	3.044	+66	+1.1
Cymene } $C_{10}H_{14}$	184.46	6970	7050	2.782	2.814	+89	+1.1

TABLE I.—*Continued.*

Substance.		V Molecular Volume.	$KV_{\text{calc}}$	$ma + nb$ + $pc + \dots$	K Observed.	K Calculated.	Difference between $KV_{\text{calc}}$ and $ma + nb + pc + \dots$	per centage Difference.
Terpene	$C_{10}H_{16}$	186.3*	6987	7200	2.748	2.832	+213	+3.0
"	"	196. ?	7166	7200	2.612	2.624	+34	+0.4
Methyl Alcohol	$\left\{ \begin{array}{l} CH_3O \\ C_2H_5O \end{array} \right.$	42.72	1066	1970	3.818	3.832	+4	+0.4
Ethyl Alcohol	$\left\{ \begin{array}{l} C_2H_5O \\ C_3H_7O \end{array} \right.$	62.19	1731	1820	3.530	3.710	+89	+5.1
Propyl Alcohol	$\left\{ \begin{array}{l} C_3H_7O \\ C_4H_9O \end{array} \right.$	81.29	2583	2570	3.524	3.596	-13	-0.5
Isopropyl Alcohol	$\left\{ \begin{array}{l} C_4H_9O \\ C_5H_{11}O \end{array} \right.$	81.69	2513	2570	3.404	3.482	+57	+2.3
Isobutyl Alcohol	$\left\{ \begin{array}{l} C_5H_{11}O \\ C_6H_{13}O \end{array} \right.$	101.64	3287	3320	3.208	3.240	+33	+1.0
Isoamyl Alcohol	$\left\{ \begin{array}{l} C_6H_{13}O \\ C_7H_{15}O \end{array} \right.$	122.74	4172	4070	3.068	2.994	-102	-2.4
Dimethyl- ethyl-carbinol	$\left\{ \begin{array}{l} C_7H_{15}O \\ C_8H_{17}O \end{array} \right.$	121.27	4140	4070	3.100	3.047	-70	-1.7
Allyl Alcohol	$\left\{ \begin{array}{l} C_3H_6O \\ C_4H_8O \end{array} \right.$	74.11	2495	2420	3.910	3.793	-75	-3.0
Methyl Formate	$\left\{ \begin{array}{l} C_2H_4O_2 \\ C_3H_6O_2 \end{array} \right.$	62.65	2452	2400	4.944	4.839	-52	-2.1
Ethyl Formate	$\left\{ \begin{array}{l} C_3H_6O_2 \\ C_4H_8O_2 \end{array} \right.$	84.57	3074	3150	3.952	4.050	+76	+2.5
Methyl Acetate	$\left\{ \begin{array}{l} C_4H_8O_2 \\ C_5H_{10}O_2 \end{array} \right.$	83.66	3076	3150	4.020	4.117	+74	+2.4
Propyl Formate	$\left\{ \begin{array}{l} C_4H_8O_2 \\ C_5H_{10}O_2 \end{array} \right.$	106.15	4058	3900	3.710	3.565	+158	+3.9
Ethyl Acetate	"	105.78	3854	3900	3.542	3.585	+46	+1.2
Methyl Pro- pionate	$\left\{ \begin{array}{l} C_5H_{10}O_2 \\ C_6H_{12}O_2 \end{array} \right.$	104.27	3815	3900	3.612	3.664	+55	+1.4
Isobutyl Formate	$\left\{ \begin{array}{l} C_5H_{10}O_2 \\ C_6H_{12}O_2 \end{array} \right.$	130.74	4829	4650	3.230	3.110	-179	-3.7

\* The molecular volume of this compound seems to be abnormally low, being 10 or 9 units less than the calculated, which accounts for the discrepancy as shown in the calculation for Table II. Still it is but fair to confess that several other substances of similar constitution have molecular volumes quite as anomalous. See Lossen's calculation of molecular volumes in Liebig's Annalen(254, 54).

TABLE I.—Continued.

Substance.	$\gamma$ Molecular Volume.	$Kr^{\frac{2}{3}}$	$ma + nb$ + $pc + \dots$	$K$ Observed.	$K$ Calculated.	Difference between $Kr^{\frac{2}{3}}$ and $ma + nb + pc + \dots$	per centage Difference.
Propyl Acetate } $C_5H_{10}O_2$	128.56	4641	4650	3.184	3.190	+9	+0.2
Ethyl Pro- pionate } "	127.83	4580	4650	3.168	3.217	+70	+1.5
Methyl Butyrate } "	126.36	4616	4650	3.250	3.274	+34	+0.7
Methyl Iso- butyrate } "	126.44	4535	4650	3.190	3.271	+115	+2.5
Isoamyl Formate } $C_6H_{12}O_2$	153.22*	5841	5400	3.080	2.847	-441	-7.5
Isobutyl Acetate } "	152.51†	5610	5400	2.978	2.867	-210	-3.3
Propyl Pro- pionate } "	150.70	5406	5400	2.922	2.919	-6	-0.1
Ethyl Butyrate } "	150.25	5356	5400	2.908	2.932	+44	+0.8
Ethyl Iso- butyrate } "	150.68	5246	5400	2.836	2.919	+154	+2.9
Methyl Valerate } "	148.33	5130	5400	3.006	2.989	-30	-0.6
Isoamyl Acetate } $C_7H_{14}O_2$	174.60	6372	6150	2.762	2.666	-222	-3.3
Isobutyl Propionate } "	173.55	6054	6150	2.648	2.690	+96	+1.6
Propyl Butyrate } "	173.85	6189	6150	2.700	2.683	-39	-0.6
Propyl Iso- butyrate } "	174.20	6056	6150	2.634	2.675	+94	+1.6
Ethyl Valerate } "	172.99	6139	6150	2.698	2.703	+11	+0.2
Isoamyl Propionate } $C_8H_{16}O_2$	196.96	6977	6900	2.524	2.496	-77	-1.1
Isobutyl Butyrate } "	197.66	6786	6900	2.442	2.483	+114	+1.7
Isobutyl Isobutyrate } "	198.21	6814	6900	2.442	2.473	+86	+1.3

\* In Lössen's paper above alluded to, this value is put=1517. The determination of Elsässer seems to be even lower than this, and as Schiff lauds very highly the purity of this chemist's investigation materials, it is highly probable that Schiff's own substance in this instance is not as pure as his usually are

† The same remark applies to this also.



TABLE I.—Continued.

Substance.		V Molecular Volume.	$KV^{\frac{2}{3}}$	$\frac{ma+nb}{+pc+\dots}$	K Observed.	K Calculated.	Difference between $KV^{\frac{2}{3}}$ and $\frac{ma+nb}{+pc+\dots}$	per cent age Difference.
Propyl Valerate	$\left. \begin{array}{l} \\ \end{array} \right\} C_8H_{16}O_2$	196.82	6969	6900	2.524	2.499	-69	-1.0
Allyl Acetate	$\left. \begin{array}{l} \\ \end{array} \right\} C_5H_8O_2$	121.5	4520	4500	3.370	3.361	-20	-0.4
Ethyl Oxalate	$\left. \begin{array}{l} \\ \end{array} \right\} C_6H_{10}O_2$	138.79	5108	4950	3.124	3.027	-158	-3.1
Methyl Benzoate	$\left. \begin{array}{l} \\ \end{array} \right\} C_8H_8O_2$	151.65	6653	6600	3.563	3.534	-53	-0.8
Ethyl Benzoate	$\left. \begin{array}{l} \\ \end{array} \right\} C_9H_{10}O_2$	174.65	7335	7350	3.178	3.184	+15	+0.2
Ethyl-oxide	$C_4H_{10}O$	106.27	3441	3600	3.142	3.287	+159	+4.6
Methyl Amyl Ether	$\left. \begin{array}{l} \\ \end{array} \right\} C_6H_{14}O$	148.13	5060	5100	2.807	2.829	+40	+0.8
Paraldehyde	$C_6H_{12}O_3$	150.74	5768	5850	3.084	3.160	+142	+2.5
Acetone	$C_3H_6O$	77.10	2636	2700	3.894	3.988	+64	+2.4
Valeraldehyde	$\left. \begin{array}{l} \\ \end{array} \right\} C_5H_{10}O$	118.27	4303	4200	3.345	3.265	-106	-2.4
Acetic Anhydride	$\left. \begin{array}{l} \\ \end{array} \right\} C_4H_6O_3$	109.5	4462	4200	3.896	3.666	-262	-5.9
Dimethyl Acetal	$\left. \begin{array}{l} \\ \end{array} \right\} C_4H_{10}O_2$	110.9	4681	4050	3.470	3.443	-31	-0.8
Diethyl Acetal	$\left. \begin{array}{l} \\ \end{array} \right\} C_6H_{14}O_2$	159.91	5444	5550	2.692	2.746	+106	+2.0
Pinacolone	$C_6H_{12}O$	138.25	5017	4950	3.086	3.040	-67	-1.5
Anisol	$C_7H_8O$	125.21	5503	5550	3.928	3.966	+47	+0.9
Phenetol	$C_8H_{10}O$	149.4	6142	6300	3.370	3.455	+158	+2.5
Methoxycresol „		147.8	6345	6300	3.531	3.506	-45	-0.7
Dimethoxy-cresol	$\left. \begin{array}{l} \\ \end{array} \right\} C_9H_{10}O_2$	157.6	7087	7050	3.598	3.582	-37	-0.5
Cinnamaldehyde	$\left. \begin{array}{l} \\ \end{array} \right\} C_9H_{12}O$	188.9	7750	7700	3.919	3.900	-50	-0.7

TABLE I.—Continued.

Substance.		$\nabla$ Molecular Volume.	$KV^{\frac{2}{3}}$	$ma + pb$ $+ pc + \dots$	$K$ Observed.	$K$ Calculated.	Difference between $KV^{\frac{2}{3}}$ and $ma + pb + pc + \dots$	per centage Difference.
Formic Acid	$\left\{ \text{CH}_2\text{O}_2 \right.$	41.08	1558	1650	5.917	?	?	?
Acetic Acid	$\text{C}_2\text{H}_4\text{O}_2$	63.49	1853	2400	3.670	?	?	?
Propionic Acid	$\left\{ \text{C}_3\text{H}_6\text{O}_2 \right.$	85.94	2558	3150	3.212	?	?	?
Butyric Acid	$\left\{ \text{C}_4\text{H}_8\text{O}_2 \right.$	108.10	3247	3900	2.886	?	?	?
Isobutyric Acid	$\left\{ \text{,,} \right.$	109.87	3162	3900	2.746	?	?	?
Valeric Acid	$\left\{ \text{C}_5\text{H}_{10}\text{O}_2 \right.$	130.27	3821	4650	2.570	?	?	?
Ethylene Chloride	$\left\{ \text{C}_2\text{H}_4\text{Cl}_2 \right.$	85.35	3816	3700	4.840	4.692	-116	-3.1
Ethidene Chloride	$\left\{ \text{,,} \right.$	88.68	3427	3350	4.104	4.012	-77	-2.3
Propyl Chloride	$\left\{ \text{C}_3\text{H}_7\text{Cl} \right.$	91.58	3263	3425	3.732	3.908	+162	+4.8
Propylene Chloride	$\left\{ \text{C}_3\text{H}_6\text{Cl}_2 \right.$	107.59	4533	4450	4.062	3.988	-83	-1.8
Isobutyl Chloride	$\left\{ \text{C}_4\text{H}_9\text{Cl} \right.$	114.29	4068	4175	3.333	3.421	+107	+2.6
Isomyl Chloride	$\left\{ \text{C}_5\text{H}_{11}\text{Cl} \right.$	134.40	4859	4925	3.118	3.161	+66	+1.4
Chloroben- zene	$\left\{ \text{C}_6\text{H}_5\text{Cl} \right.$	114.4	5053	5075	4.128	4.146	+22	+0.4
Chloro- toluene	$\left\{ \text{C}_7\text{H}_7\text{Cl} \right.$	134.9	5848	5825	3.734	3.719	-23	-0.4
Chloroform	$\text{CHCl}_3$	84.65	3443	3450	4.420	4.430	+7	+0.2
Carbonte- trachloride	$\left\{ \text{CCl}_4 \right.$	103.77	4313	4300	4.080	4.068	-13	-0.3
Bromine	$\text{Br}_2$	53.52	2792	3000	7.132	7.663	+208	+7.4
Ethyl Bromide	$\left\{ \text{C}_2\text{H}_5\text{Br} \right.$	77.07	3094	3075	4.443	4.543	+71	+2.3
Ethylene Bromide	$\left\{ \text{C}_2\text{H}_4\text{Br}_2 \right.$	97.01	4900	4500	5.128	4.710	-400	-8.1

TABLE I.—*Continued.*

Substance.	$V$ Molecular Volume.	$KV^{\frac{2}{3}}$	$ma + nb$ $+ pc + \dots$	$K$ Observed.	$K$ Calculated.	Difference between $KV^{\frac{2}{3}}$ and $ma + nb + pc + \dots$	per centage Difference
Propyl Bromide } $C_3H_7Br$	97.05	3830	3825	4.007	4.001	-5	-0.2
Isopropyl Bromide } „	99.2	3814	3825	3.861	3.871	+11	+0.3
Allyl Bromide } $C_3H_5Br$	90.5	3731	3675	4.334	4.269	-56	-1.5
Isobutyl Bromide } $C_4H_9Br$	118.39	4613	4575	3.581	3.552	-38	-0.8
Bromo-benzene } $C_6H_5Br$	119.88	5518	5475	4.204	4.171	-43	-0.8
Bromo-toluene } $C_7H_7Br$	141.95	6359	6225	3.773	3.694	-134	-2.1
Methyl Iodide } $CH_3I$	63.9	2864	2975	5.607	5.824	+111	+4.0
Ethyl Iodide } $C_2H_5I$	86.12	3666	3725	4.587	4.661	+59	+1.6
Propyl Iodide } $C_3H_7I$	106.9	4509	4475	4.080	4.049	-34	-0.8
Isobutyl Iodide } $C_4H_9I$	128.28	5265	5225	3.624	3.595	-40	-0.8
Isoamyl Iodide } $C_5H_{11}I$	151.05	6000	5975	3.232	3.219	-25	-0.4
Allyl Iodide } $C_3H_5I$	100.9	4415	4325	4.358	4.271	-90	-2.0
Iodobenzene } $C_6H_5I$	130.55	6217	6125	4.168	4.106	-92	-1.5
Propylamine } $C_3H_7N$	85.61	3105	3125	3.920	3.945	+20	+0.6
Allylamine } $C_3H_7N$	78.38	2970	2975	4.290	4.298	+5	+0.2
Isobutyl-amine } $C_4H_{11}N$	106.76	3930	3875	3.563	3.513	-55	-1.4
Diethylamine } „	109.05	3795	3875	3.333	3.403	+80	+2.1
Amylamine } $C_5H_{13}N$	126.84	4829	4625	3.380	3.238	-204	-4.3
Triethyl-amine } $C_6H_{15}N$	153.82	5259	5375	2.756	2.817	+116	+2.2

TABLE I.—Continued.

Substance.		$V$ Molecular Volume.	$KV^{\frac{2}{3}}$	$\frac{ma+nb}{+pc+.....}$	$K$ Observed.	$K$ Calculated.	Difference between $KV^{\frac{2}{3}}$ and $\frac{ma+nb}{+pc+.....}$	per centage Difference.
Aniline	$C_6H_7N$	106.08	5168	5075	4.730	4.645	-93	-1.8
Pyridene	$C_5H_5N$	89.39	4137	4325	4.895	5.116	+188	+4.5
Piperidene	$C_5H_{11}N$	108.70	4693	4775	4.138	4.208	+82	+1.7
Quinoline	$C_9H_7N$	139.75	7355	7175*	4.452	4.343	-180	-2.4
Nitro- methane	$\left\{ CH_3NO_2 \right.$	59.5	2390	2375	5.207	5.175	-15	-0.6
Nitroethane	$C_2H_5NO_2$	80.25	3070	3125	4.271	4.347	+55	+1.7
Isoamyl- nitrate	$\left\{ C_5H_{11}NO_3 \right.$	152.59	5923	5825	3.142	3.091	-98	-1.6
Acetonitrile	$C_2H_3N$	57.23	1873	1875	4.327	4.331	+2	+0.1
Propionitrile	$C_3H_5N$	78.28	2649	2625	3.825	3.790	-24	-0.8
Capronitrile	$C_6H_{11}N$	141.1	5345	4875	3.189	2.909	-470	-9.0
Ethyl Sulphide	$\left\{ C_4H_{10}S \right.$	122.2	4622	4650	3.420	3.440	+28	+0.6
Allyl Thio- carbimide	$\left\{ C_4H_7NS \right.$	123.13	5046	4925	4.193	4.092	-121	-2.4
Phenyl thio- carbimide	$\left\{ C_7H_5NS \right.$	143.7	7021	7025	4.077	4.081	+4	+0.05
Methyl thio- cyanate	$\left\{ C_2H_5NS \right.$	78.96	3329	3375	4.745	4.816	+46	+1.5
Ethyl thio- cyanate	$\left\{ C_3H_5NS \right.$	99.84	4166	4125	4.176	4.135	-41	-1.0
Carbon Bisulphide	$\left\{ CS_2 \right.$	62.06	2842	2900	5.813	5.930	+58	+2.0

\*  $9 \times 600 + 7 \times 75 + 650 = 6575$   $6575 + 2 \times 300 = 7175$ . But this mode of calculation is probably incorrect.

The Atomic constants ( $a'$   $b'$   $c'$ ) for the various elements used in the calculation of the second table are as follows :

- for carbon 44 when there is no double linking.  
 „ hydrogen 21.5 in all cases.  
 „ oxygen 31 in alcohols.  
 „ „ 44 when combined with two carbon atoms.  
 „ „ 55 when connecting a carbon atom to a benzene ring.  
 „ chlorine 119 when only one atom of chlorine is united with a carbon atom.  
 „ chlorine 110 when two or more atoms of chlorine are united with a carbon atom.  
 „ bromine 162 when only one atom of bromine is united with a carbon atom.  
 „ iodine 215 when only one atom of iodine is united with a carbon atom.  
 „ nitrogen 54 in all cases where it is a triad.  
 „ sulphur 148 when combined with two carbon atoms.

When two atoms are united together by more than one bond, the value of  $K^{\frac{1}{2}}F^{113}$  is increased by 19 for each additional bond. Thus :

$$\text{group } (\diagup C = C \diagdown) = 107 = 2 \times 44 + 19$$


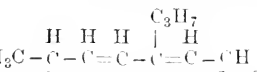
$$\text{group } (\diagup C = O) = 118 = 44 + 55 + 19$$

$$\text{group } (-C \equiv N) = 136 = 44 + 54 + 2 \times 19$$

$$\text{group } (-N = C = S) = 284 = 44 + 54 + 19 + 148 + 19$$

$$\left. \begin{array}{l} \text{group } (SCN) = 270 \\ \text{group } (NO_2) = 172 \end{array} \right\} \text{these have not been resolved.}$$

TABLE II.

Substance.	K.	V Molecular Volume.	$K^{\frac{1}{3}}_{\text{gas}}$ .	$\frac{nd'}{V} + \frac{nb'}{V} + \dots$	Difference between $K^{\frac{1}{3}}_{\text{gas}}$ and $\frac{nd'}{V} + \frac{nb'}{V} + \dots$	per centage Difference.
Normal Hexane $\text{C}_6\text{H}_{14}$	2.772	140.02	567	565	- 2	-0.35
Normal Heptane $\text{C}_7\text{H}_{16}$	2.575	162.56	652	652	$\pm$ 0	$\pm$ 0.00
Diisobutyl $(\text{C}_4\text{H}_9)_2$	2.410	184.89	734	739	+ 5	+0.68
Diisoamyl $(\text{C}_5\text{H}_{11})_2$	2.192	231.80	915	913	- 2	-0.22
Amylene $\text{C}_5\text{H}_{10}$	3.082	110.18	451	454	+ 3	+0.66
Octylene $\text{C}_8\text{H}_{16}$	2.572	177.61	723	715	- 8	-1.11
Diallyl $\text{H}_2\text{C}=\text{C}(\text{H})-\text{CH}_2-\text{C}(\text{H})=\text{CH}_2$	3.008	126.10	521	517	- 4	-0.77
Benzene 	4.254	96.17	451	450	- 1	-0.22
Toluene $\text{HC}(\text{H})=\text{C}(\text{H})-\text{C}(\text{H})=\text{C}(\text{H})-\text{CH}_3$	3.692	118.25	536	537	+ 1	+0.19
Nylene (1 : 2) $\text{C}_8\text{H}_{10}$	3.354	139.91	624	624	$\pm$ 0	$\pm$ 0.00
„ (1 : 3) „	3.358	139.69	623	624	+ 1	+0.16
„ (1 : 4) „	3.340	140.21	624	624	$\pm$ 0	$\pm$ 0.00
Ethyl Benzene $\text{C}_6\text{H}_5.\text{C}_2\text{H}_5$	3.420	138.96	624	624	$\pm$ 0	$\pm$ 0.00
Propyl Benzene $\text{C}_6\text{H}_5.\text{C}_3\text{H}_7$	3.122	161.82	714	711	- 3	-0.42
Ethyl Toluene $\text{C}_6\text{H}_4.\text{CH}_3.\text{C}_2\text{H}_5$	3.092	161.95	712	711	- 1	-0.14
Mesitylene (1 : 3 : 5) $\text{C}_6\text{H}_3(\text{CH}_3)_3$	3.012	162.41	705	711	+ 6	+0.85
Cymene (1 : 5) $\text{C}_6\text{H}_4(\text{CH}_3)(\text{C}_3\text{H}_7)$	2.782	184.46	787	798	+11	+1.40
Terpene (citrene) 	2.748	183.3 *	791	822	+31	+4.

\* For the peculiarity of the molecular volume of this compound, see the foot-note annexed to the foregoing table.

TABLE II.—Continued.

Substance.	K.	$V$ Molecular Volume.	$K^{\frac{1}{2}}p_{118}$ .	$ma' + nb'$ $+ pe' + \dots\dots$	Difference: between $K^{\frac{1}{2}}p_{118}$ and $ma + nb + pe + \dots\dots$	per centage Difference.
Terpene (citrene) $\left\{ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{C}_3\text{H}_7 \\   \quad   \quad   \quad   \\ \text{H}_3\text{C}-\text{C}-\text{C}=\text{C}-\text{C}=\text{C}-\text{CH}_2 \end{array} \right.$	2.624	196.	819	822	+ 3	+0.37
Methyl Alcohol $\text{CH}_3\text{OH}$	3.818	42.72	164	161	- 3	-1.83
Ethyl Alcohol $\text{C}_2\text{H}_5\text{OH}$	3.530	62.19	246	248	+ 2	+0.81
Propyl Alcohol $\text{C}_3\text{H}_7\text{OH}$	3.524	81.29	337	335	- 2	-0.59
Isopropyl Alcohol $(\text{C}_3\text{H}_7)^i\text{OH}$	3.494	81.69	333	335	+ 2	+0.60
Isobutyl Alcohol $(\text{C}_4\text{H}_9)^i\text{OH}$	3.208	101.64	418	422	+ 4	+0.95
Isoamyl Alcohol $(\text{C}_5\text{H}_{11})^i\text{OH}$	3.068	122.74	511	509	- 2	-0.40
Dimethyl Ethyl Carbinol $\left\{ \text{C}_5\text{H}_{12}\text{O} \right.$	3.100	121.27	506	509	+ 3	+0.60
Allyl Alcohol $\text{H}_2\text{C}=\text{CH}-\text{CH}_2\text{OH}$	3.910	74.11	318	311	- 7	-2.20
Methyl Formate $\text{HCO}_2\text{CH}_3$	4.944	62.65	293	292	- 1	-0.34
Ethyl Formate $\text{HCO}_2\text{C}_2\text{H}_5$	3.952	84.57	374	379	+ 5	+1.34
Methyl Acetate $\text{H}_3\text{C}_2\text{O}_2\text{CH}_3$	4.020	83.66	372	379	+ 7	+1.88
Propyl Formate $\text{HCO}_2\text{C}_3\text{H}_7$	3.710	106.15	474	466	- 8	-1.68
Ethyl Acetate $\text{H}_3\text{C}_2\text{O}_2\text{C}_2\text{H}_5$	3.542	105.78	461	466	+ 5	+1.08
Methyl Propionate $\text{H}_3\text{C}_3\text{O}_2\text{CH}_3$	3.612	104.27	457	466	+ 9	+1.97
Isobutyl Formate $\text{HCO}_2(\text{C}_4\text{H}_9)^i$	3.230	130.74	565	553	-12	-2.12
Propyl Acetate $\text{H}_3\text{C}_2\text{O}_2\text{C}_3\text{H}_7$	3.184	128.56	559	553	+ 3	+0.60
Ethyl Propionate $\text{H}_3\text{C}_3\text{O}_2\text{C}_2\text{H}_5$	3.168	127.86	545	553	+ 8	+1.45
Methyl Butyrate $\text{H}_7\text{C}_4\text{O}_2\text{CH}_3$	3.250	126.86	544	553	+ 9	+1.65

TABLE II.—*Continued.*

Substance.	K.	$\Gamma$ Molecular Volume.	$K^2/\Gamma$ .	$\frac{m'}{p} + \frac{m''}{p} + \dots$	Difference between $\frac{K^2}{\Gamma}$ and $\frac{m'}{p} + \frac{m''}{p} + \dots$	per centage Difference.
Methyl Isobutyrate ( $\text{H}_7\text{C}_4\text{O}_2$ ) $\text{C}_2\text{H}_5$	3.199	126.44	510	553	+13	+2.41
Isoamyl Formate $\text{HCO}_2\text{C}_5\text{H}_{11}$	3.080	153.22	665	619	-25	-3.76
Isobutyl Acetate $\text{H}_5\text{C}_2\text{O}_2\text{C}_4\text{H}_9$	2.978	152.51	651	649	-11	-1.69
Propyl Propionate $\text{H}_5\text{C}_3\text{O}_2\text{C}_3\text{H}_7$	2.922	150.79	635	610	+ 5	+0.79
Ethyl Butyrate $\text{H}_7\text{C}_4\text{O}_2\text{C}_2\text{H}_5$	2.908	150.25	632	610	+ 8	+1.27
Ethyl Isobutyrate ( $\text{H}_7\text{C}_4\text{O}_2$ ) $\text{C}_2\text{H}_5$	2.836	150.68	623	610	+14	+2.23
Methyl Valerate $\text{H}_5\text{C}_3\text{O}_2\text{CH}_3$	3.006	148.33	632	610	+ 8	+1.27
Isoamyl Acetate $\text{H}_5\text{C}_2\text{O}_2\text{C}_5\text{H}_{11}$	2.762	171.60	735	727	- 8	-1.09
Isobutyl propionate $\text{H}_5\text{C}_3\text{O}_2\text{C}_4\text{H}_9$	2.648	173.55	711	727	+13	+1.82
Propyl Butyrate $\text{H}_7\text{C}_4\text{O}_2\text{C}_3\text{H}_7$	2.799	173.85	723	727	+ 4	+0.55
Propyl Isobutyrate ( $\text{H}_7\text{C}_4\text{O}_2$ ) $\text{C}_3\text{H}_7$	2.634	171.29	716	727	+11	+1.54
Ethyl Valerate ( $\text{H}_5\text{C}_3\text{O}_2$ ) $\text{C}_2\text{H}_5$	2.698	172.99	718	727	+ 9	+1.25
Isoamyl Propionate $\text{H}_5\text{C}_3\text{O}_2\text{C}_5\text{H}_{11}$	2.524	193.96	819	814	+ 4	+0.49
Isobutyl Butyrate $\text{H}_7\text{C}_4\text{O}_2\text{C}_4\text{H}_9$	2.442	197.63	809	814	+14	+1.73
Isobutyl Isobutyrate) ( $\text{H}_7\text{C}_4\text{O}_2$ ) $\text{C}_4\text{H}_9$	2.442	198.21	803	814	+11	+1.38
Propyl Valerate $\text{H}_5\text{C}_3\text{O}_2\text{C}_4\text{H}_9$	2.524	196.82	809	814	+ 5	+0.62
Allyl Acetate $\text{H}_5\text{C}_2\text{O}_2\text{C}_3\text{H}_5$	3.379	121.5	529	529	$\pm 0$	$\pm 0.00$
Ethyl Oxalate $\text{C}_2\text{O}_4\text{C}_2\text{H}_5$	3.124	138.79	739	716	-23	-3.11
Methyl Benzoate $\text{C}_7\text{H}_5\text{O}_2\text{CH}_3$	3.533	151.65	797	699	- 8	-1.13
Ethyl Benzoate $\text{C}_7\text{H}_5\text{O}_2\text{C}_2\text{H}_5$	3.178	171.65	789	786	- 3	-0.38



TABLE II.—Continued.

Substance.	$K$ .	$\Gamma$ Molecular Volume.	$K^{\frac{1}{2}} \Gamma^{1/4}$ .	$\frac{m}{m'} + \frac{nb'}{pe'} + \dots$ .	Difference between $K^{\frac{1}{2}} \Gamma^{1/4}$ and $\frac{m}{m'} + \frac{nb'}{pe'} + \dots$ .	per centage Difference.
Ethyl Oxide $(C_2H_5)_2O$	3.142	106.27	436	435	— 1	—0.23
Methyl Amyl Ether $C_5H_{11}OCH_3$	2.897	148.13	610	609	— 1	—0.16
Paraldehyde $\left\{ \begin{array}{c} \text{H}_3\text{C}-\text{C} \begin{array}{l} \nearrow \text{O} \searrow \\ \text{H} \quad \text{O} \end{array} \text{C}-\text{CH}_3 \\ \text{H} \quad \text{H} \end{array} \right.$	3.084	159.74	654	654	$\pm 0$	$\pm 0.00$
Dimethyl Acetal $\begin{cases} \text{H}_2=\text{C}-\text{O}-\text{CH}_3 \\ \text{H}_2=\text{C}-\text{O}-\text{CH}_3 \end{cases}$	3.470	110.9	484	480	— 4	—0.83
Diethyl Acetal $\begin{cases} \text{H}_2=\text{C}-\text{O}-\text{C}_2\text{H}_5 \\ \text{H}_2=\text{C}-\text{O}-\text{C}_2\text{H}_5 \end{cases}$	2.692	159.91	654	653	— 1	—0.15
Acetone $\text{H}_3\text{C}-\text{CO}-\text{CH}_3$	3.894	77.10	333	335	+ 2	+0.60
Valeraldehyde $C_5H_{10}O$	3.315	118.27	511	509	— 2	—0.39
Pinacoline $(\text{CH}_3)_3\text{CO}.\text{CH}_3$	3.086	138.25	591	596	+ 5	+0.84
Acetic Anhydride $(C_2H_3O)_2O$	3.896	109.5	503	498	— 5	—0.99
Anisol $C_6H_5OCH_3$	3.928	125.21	592	592	$\pm 0$	$\pm 0.00$
Phenetol $C_6H_5OC_2H_5$	3.370	149.4	675	679	+ 4	+0.59
Methoxycresol $C_6H_4(\text{OCH}_3)\text{CH}_3$	3.531	147.8	683	679	— 4	—0.58
Dimethoxycresol $C_6H_4(\text{OCH}_3)_2$	3.598	157.6	741	734	— 7	—0.95
Cuminaldehyde $(\text{CH}_3)_2\text{CH}.\text{C}_6\text{H}_4\text{CHO}$	3.019	188.9	837	829	— 8	—0.95
Carvol $\left\{ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{C}_3\text{H}_7\text{H} \\ \text{CH}_3-\text{C}-\text{C}=\text{C}-\text{C}=\text{C}-\text{CO} \end{array} \right.$	3.169	190.26	872	853	—19	—2.18
Formic Acid $\text{HCOOH}$	5.917	41.08	195	205	?	

TABLE II.—*Continued.*

Substance.		K.	F Molecular Volume.	$K^2/18.$	$mb + nb$ + $pc + \dots$	Difference between $K^2/18$ and $mb + nb + pc + \dots$		per centage Difference.
Acetic Acid	$C_2H_4O_2$	3.670	63.40	256	292	?		
Propionic Acid	$C_3H_6O_2$	3.212	85.94	343	379	?		
Butyric Acid	$C_4H_8O_2$	2.886	108.10	427	466	?		
Isobutyric Acid	,,	2.746	109.87	424	466	?		
Valeric Acid	$C_5H_{10}O_2$	2.570	130.27	502	553	?		
Ethylene Chloride	$(CH_2Cl)_2$	4.840	85.35	418	412	— 6	— 1.44	
Ethidene Chloride	$H_3C-CHCl_2$	4.104	88.68	403	394	— 9	— 2.23	
Propyl Chloride	$C_3H_7Cl$	3.732	91.58	399	402	+ 3	+ 0.75	
Propylene Chloride	$C_3H_6Cl_2$	4.062	107.59	503	499	— 4	— 0.79	
Isobutyl Chloride	$(C_4H_9)_2Cl$	3.333	114.20	489	489	$\pm 0$	$\pm 0.00$	
Isoamyl Chloride	$(C_5H_{11})_2Cl$	3.118	134.40	573	576	+ 3	+ 0.52	
Chlorobenzene	$C_6H_5Cl$	4.128	111.4	546	548	+ 2	+ 0.37	
Chlorotoluene	$H_3C.C_6H_4Cl$	3.734	134.9	630	635	+ 5	+ 0.79	
Chloroform	$CHCl_3$	4.420	84.65	396	396	$\pm 0$	$\pm 0.00$	
Carbon Tetrachloride	$\left. \begin{array}{l} \\ \end{array} \right\} CCl_4$	4.080	103.77	483	484	+ 1	+ 0.21	
Bromine	$Br_2$	7.132	53.52	293	—	?	?	
Ethyl Bromide	$C_2H_5Br$	4.443	77.07	355	358	+ 3	+ 0.84	
Ethylene Bromide	$(CH_2Br)_2$	5.128	97.01	501	499	— 2	— 0.40	

TABLE II.—Continued.

Substance.	K.	$\frac{1}{V}$ Molecular Volume.	$K^2 \frac{1}{V^2}$	$ma + mb + pc + \dots$	Difference between $K^2 \frac{1}{V^2}$ and $ma + mb + pc + \dots$	per centage Difference.
Propyl Bromide $C_3H_7Br$	4.007	97.05	443	445	+ 2	+0.45
Isopropyl Bromide $(C_3H_7)^2Br$	3.831	99.2	446	445	— 1	—0.23
Allyl Bromide $C_3H_5Br$	4.334	90.5	424	420	— 4	—0.94
Isobutyl Bromide $(C_4H_9)^2Br$	3.581	118.39	529	531	+ 2	+0.38
Bromobenzene $C_6H_5Br$	4.204	119.88	582	580	— 2	—0.35
Bromotoluene $H_3C.C_6H_4Br$	3.773	141.95	671	667	— 4	—0.59
Methyl Iodide $CH_3I$	5.607	63.9	320	324	+ 4	+1.25
Ethyl Iodide $C_2H_5I$	4.587	86.12	411	411	$\pm$ 0	$\pm$ 0.00
Propyl Iodide $C_3H_7I$	4.080	106.9	501	498	— 3	—0.60
Isobutyl Iodide $(C_4H_9)^2I$	3.624	128.28	585	585	$\pm$ 0	$\pm$ 0.00
Isoamyl Iodide $(C_5H_{11})^2I$	3.232	151.05	670	672	+ 2	+0.30
Allyl Iodide $\left( \begin{smallmatrix} H & H_2 \\   &   \\ H_2C & C-C \end{smallmatrix} \right) I$	4.358	100.9	483	474	— 9	—1.86
Iodobenzene $C_6H_5I$	4.168	130.55	641	644	+ 3	+0.47
Propylamine $C_3H_7.NH_2$	3.929	85.61	378	380	+ 2	+0.53
Allylamine $C_3H_5NH_2$	4.290	78.38	356	356	$\pm$ 0	$\pm$ 0.00
Isobutylamine $(C_4H_9)^2NH_2$	3.563	106.76	467	467	$\pm$ 0	$\pm$ 0.00
Diethylamine $(C_2H_5)_2NH$	3.333	109.05	463	467	+ 4	+0.86
Triethylamine $(C_2H_5)_3N$	2.756	153.82	632	644	+ 12	+1.42
Aniline $C_6H_5NH_2$	4.730	106.08	533	526	— 7	—1.31

TABLE II.—Continued.

Substance.	$K$ .	$V$ Molecular Volume.	$K^{\frac{1}{2}}/10^3$ .	$\frac{aa' + bb'}{K^{\frac{1}{2}}/10^3} + \dots\dots\dots$	Difference between $K^{\frac{1}{2}}/10^3$ and $\frac{aa' + bb'}{K^{\frac{1}{2}}/10^3} + \dots\dots\dots$	per centage Difference.
Pyridine $\left\{ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \quad   \\ \text{C} - \text{N} - \text{C} - \text{C} - \text{C} \end{array} \right.$	4.895	89.39	444	439	— 5	—1.12
Piperidine $\left\{ \begin{array}{c} \text{H} \quad \text{H}_2 \quad \text{H}_2 \quad \text{H}_2 \\   \quad   \quad   \quad   \\ \text{H}_2\text{C} - \text{N} - \text{C} - \text{C} - \text{C} - \text{CH}_2 \end{array} \right.$	4.138	108.76	515	511	— 4	—0.78
Quinoline $\left\{ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \\ \text{N} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} \\   \quad   \quad   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array} \right.$	4.452	139.75	717	696	—21	—2.93
Nitromethane $\text{CH}_3\text{NO}_2$	5.207	59.5	283	281	— 2	—0.70
Nitroethane $\text{C}_2\text{H}_5(\text{NO}_2)$	4.271	80.25	365	368	+ 3	+0.82
Isoamyl Nitrate $\text{C}_5\text{H}_{11}\text{O}(\text{NO}_2)$	3.142	152.59	668	673	+ 5	+0.75
Acetonitrile $\text{CH}_3\text{C} \equiv \text{N}$	4.327	57.23	247	245	— 2	—0.81
Propionitrile $\text{C}_2\text{H}_5\text{C} \equiv \text{N}$	3.825	78.28	336	332	— 4	—1.19
Capronitrile $\text{C}_5\text{H}_{11}\text{C} \equiv \text{N}$	3.489	111.1	614	593	—21	—3.42
Allyl thiocarbimide $\text{C}_3\text{H}_5-\text{N}=\text{C}=\text{S}$	4.193	113.13	543	543	$\pm 0$	$\pm 0.00$
Phenyl thiocarbimide $\left\{ \begin{array}{c} \text{C}_6\text{H}_5-\text{N}=\text{C}=\text{S} \end{array} \right.$	4.077	113.7	709	713	+ 4	+0.57
Methyl thiocyanate $\text{CH}_3(\text{S}.\text{CN})$	4.745	78.96	378	379	+ 1	+0.26
Ethyl thiocyanate $\text{C}_2\text{H}_5(\text{S}.\text{CN})$	4.176	99.84	467	466	— 1	—0.21
Ethyl Sulphide $(\text{C}_2\text{H}_5)_2\text{S}$	3.420	122.2	537	539	+ 2	+0.37

TABLE II.—Continued.

Substance.		$K$ .	$V$ Molecular Volume.	$K^{\frac{1}{2}}V^{1.18}$ .	$ma' + nb'$ $+ pc' + \dots\dots\dots$	Difference between $K^{\frac{1}{2}}V^{1.18}$ and $ma + nb$ $\epsilon + \dots\dots\dots$	per centage Difference.
Water	H <sub>2</sub> O	11.935*	18.74	110	98	?	

The average difference between the observed and the calculated values of  $KV^{\frac{3}{2}}$ , and therefore of  $K$ , in the first table is  $\pm 1.85\%$ ; while the similar difference in the values of  $K^{\frac{1}{2}}V^{1.18}$  in the second table is not more than  $0.90\%$ , the agreement being much closer. The value of  $K$  calculated therefrom is, however, again about the same as that in the first table, viz.,  $1.8\%$ .

These results are more satisfactory than those obtained by Schiff's formula, which gives values of  $N$  differing from the observed values by  $3.5\%$  on the average; and as  $N$  is proportional to  $K$ , it may be observed that the average difference between the experimental and the calculated values of  $K$  according to the formulæ here proposed is only one-half of the similar difference which obtains between the values of  $N$  when Schiff's formula is employed. In the first table there are four instances of great discrepancies, ranging from  $7.4$  to  $9.0\%$ . Of these, isoamyl-formate has an exceptionally large value for  $K$ , it being about  $6\%$  higher than the average value of four of its isomers, while its molecular volume given by Schiff seems to be too high by two per cent., so that there is some reason to believe that a careful redetermination of these data might remove this discrepancy. The next case is bromine, of which it is sufficient to remark that this element might possibly have two capillary constants as its brother

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\* This is calculated from Frankenheim's determination.

element chlorine, whose lower value applies to the cases where two or more atoms of chlorine are closely united together. Of the remaining two abnormal cases, ethylenedibromide and capronitrile, I have no remark to offer. They must be looked upon as genuine exceptions. In the second table the discrepancies are much smaller except in the case of bromine, but the remark made above about this element applies here also. The acids form an important group of exceptions in both tables as well as in Schiff's paper: this is probably owing to the abnormality of their molecular magnitude at the boiling points, and it would be strange indeed if the capillary phenomena did not show an analogous abnormality.

The atomic capillary constants above given must be regarded as only rough approximations. The values for carbon, hydrogen, chlorine, bromine, iodine, &c.....in the first table may be higher or lower than the true values by 50 units, while the difference may be greater in other elements. The values of atomic capillary constants used in the calculation of the second table seem to be much closer to the true values, and may be assumed to be correct within 5 units. A better determination of these constants, or a better choice of the coefficient of  $V$ , may give much better results than have been obtained from the calculations given above.

The first formula can be applied to the approximate determination of the molecular magnitude of a liquid compound, provided its percentage composition as well as the probable nature of its atomic concatenation, the capillary height ( $h$ ) for a tube of known internal perimeter at the boiling point, and the specific gravity ( $\rho$ ) at the same temperature are known. Suppose the empirical formula of the liquid to be  $A_m B_n C_p$ ....., where  $m'$ ,  $n'$ ,  $p'$ ..... may be integral or fractional: put this mass= $M$  and divide it by  $\rho$ , and designate the quotient by  $V'$ . Further, suppose the true molecular mass= $xM$ .

Then by the formula we have

$$h\rho = K = \frac{x(m'a + n'b + p'e + \dots)}{x^{\frac{3}{2}}V'^{\frac{3}{2}}}. \quad \text{Hence } x^{\frac{1}{2}} = \frac{m'a + n'b + p'e + \dots}{KV'^{\frac{3}{2}}}$$

$$\text{or } x = \frac{(m'a + n'b + p'e + \dots)^2}{K^2V'^3}.$$

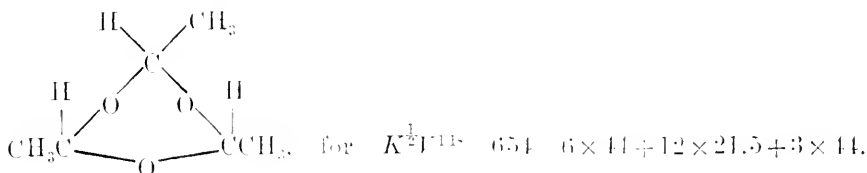
For example, toluene contains 91.3 % of carbon and 8.7 % of hydrogen ; dividing the one by 11.97, and the other by unity, we get the empirical formula  $C_{7.63}H_{8.7} = M = 100$ . The specific gravity at the boiling point is 0.776, so that  $V' = 128.8$  and the observed value of  $K$  is 3.692. Substituting these values in the above formula we have

$$x = \frac{(7.63 \times 600 + 8.7 \times 75)^2}{(3.692)^2 \times (128.8)^3} = .939.$$

Therefore, the molecular magnitude is  $C_{7.63 \times .939}H_{8.7 \times .939} = C_{7.14}H_{8.16}$ . This result is too high by 2 %, inasmuch as the calculated and the observed values of  $K$  show a difference of 1.1 %. If this difference be 2 % as it is most likely to be, then the molecular magnitude would differ by 4 %, which may be regarded as fairly approximate. But whenever this mode of determining molecular magnitude is applicable, the vapor density method can also be employed, so that this application of capillary determination is more curious than useful.

The second formula seems to be of greater interest to chemists, for it shows the close relationship between the mode of atomic linking and the capillary phenomena. It can be applied with caution to determine the number of double bonds in carbon compounds, for whenever there is one the value of  $K^{\frac{1}{2}}V'^{1.18}$  is increased by about 19 units, which is quite a large quantity compared with the probable discrepancy between the observed and the calculated values of  $K^{\frac{1}{2}}V'^{1.18}$ . Benzene has three double bonds according to this mode of calculation, while allyl compounds seem to have only one such bond. This is in accordance with the conclusion of Bruhl from optical determination.

In the case of terpene, if we assume  $F=196$ , then the result agrees with Bruhl's investigation, but if  $F=186.3$  then there can be no double bond, or at most only one. Quinoline has only five double bonds according to the accepted formula, while the calculation from the capillary height indicates six such linkings. Carvol also shows a similar peculiarity. The capillary value of the oxygen atom varies in a very peculiar manner; in alcohols it is only 31, in ethers and acials it is 44, while it attains its seemingly normal value in aromatic compounds where it is 55. In aldehydes and acetones it is  $74-55+19$ . The calculation according to this formula seems to justify the commonly accepted constitution of paraldehyde



It may be objected that the value for the group  $(C-C) = 107$  has been obtained by making the value for hydrogen too high, and that the conclusion about the atomic linking arrived at in this way is not trustworthy. But the agreement between the observed and the calculated values of  $K^{\frac{1}{2}}F^{115}$  for piperidine which has no double bond, but which has two atoms of hydrogen less than what a saturated compound ought to have, seems to prove the correctness of the above conclusion. When well worked out the capillary phenomena are likely to afford some insight into the atomic grouping of a molecule, but this can not be attempted with confidence until more accurate data are amassed.

So far the claim of the formula seems to be fairly made out, still there are many grave considerations which tend to show that the connections expressed by the equations are more accidental than



essential, and warn us not to theorize too freely from any such hasty generalization. That there are more than one formulæ, which have no essential relation to each other, to express one and the same connection, seems in itself to be a strong proof of their being of an accidental nature. A thing ( $A$ ) may depend entirely on another ( $B$ ); but if ( $B$ ) can influence a third ( $C$ ), or is always (or even usually) accompanied by it, then the proposition connecting ( $A$ ) and ( $C$ ) will sometimes have the appearance of a law. If it holds good for a great number of instances, then it may be assumed to be true within certain limits, and can be used as a sort of a law, though theoretically it is not. Just as, in using a circle of a certain radius to represent a short piece of almost any curve, we must assign a strict limit to the length of the substituted arc lest the error grow inadmissively large; so here, these accidental laws must not be stretched too far. The formulæ developed in this paper do not apply to the case of water. This may be owing to the fact that water has a very small molecular magnitude compared with the substances treated of in this paper, so that it does not lie within the limit of applicability of the formulæ. Or it may be due to the fact that water has a critical temperature so abnormally high that it is not comparable with other substances at the temperature at which the vapor pressure is equal to a certain fixed quantity. Or it may be due to some unknown cause, as is the case with the magnetic rotation of light, where water has a far greater value than can be inferred from its composition. But one thing is certain that this abnormally high capillary constant for water is not due to the complexity of its molecular structure, for the larger the molecule, the less must be the capillary attraction, supposing the formulæ to be true. This difficulty can, of course, be eluded by giving oxygen combined with two hydrogen atoms a certain arbitrary value, so as to make the calculated value of  $K$  agree with the observed. This,

however, is begging the whole question, for there is no other compound with which to test the validity of this particular value. Schiff's formula is far better than the new ones in this instance, for the extrapolated value of  $N$  for water seems to agree tolerably well with the actual value.

The next thing to be considered is the mode of measuring the constant. The capillary height multiplied by the specific gravity and divided by 2 does not represent the capillary constant or the surface tension; for according to the theory of capillary attraction  $\rho V = Tl \cos i$  or  $V = a^2 l \cos i$ , where  $V$  is the volume of the liquid raised in the tube,  $\rho$  is the density,  $l$  the internal perimeter of the tube,  $T$  the surface tension,  $a^2$  the capillary constant,  $i$  the contact angle. When a circular tube is used as in the experiment of Schiff and most other investigators,  $l (=2\pi r)$  might be measured with fair approximation;  $V$  can also be found out with tolerable accuracy, but it is next to an impossibility to measure  $i$  in the tube method. As has been criticized by Volkmann, Schiff made an unwarrantable assumption that  $i$  is always zero in the liquids investigated by him, and calculated out  $a^2$  accordingly. But as the value of  $i$  in the various liquids investigated by Schiff appears to be pretty large, especially in the case of chloroform, what he calls the capillary constant of a substance at the boiling point cannot be accepted as such indiscriminately; and the more so, since, as he himself points out,  $i$  changes with rise of temperature, and since the boiling points of many liquids given in his communications are somewhat high.  $i$  cannot be zero even where it is so at ordinary temperatures. Volkmann has calculated the value of  $i$  for all the liquids contained in the first communication of Schiff's, from the height of the meniscus given in the paper. But, as Schiff replies, the meniscus height is undoubtedly one of the most difficult of quantities to measure. Indeed, the recalculation made by Volkmann

cannot be looked upon as an improvement, for according to it the value of  $i$  for hydrocarbons is sometimes very considerable, while that for chloroform is very small. Empirically, Schiff's work is of great value, for whatever may be the value of  $i$ , the capillary height  $h$  is a well defined quantity and can be accurately measured, and the relation found between capillary height and chemical composition is valid whether the constant is theoretically correct or not. Still from a strictly scientific point of view, the investigation must be deemed very imperfect, involving, as it does, an incorrect method of calculation. It is, therefore, very desirable that the matter should be investigated anew with an entirely different method, if possible, so as to confirm Schiff's work, and to remove all inaccuracies as far as practicable. The tube method is said to be the most accurate, still there is the drawback above alluded to. The plate and bubble method of Quincke is theoretically good, but practically the results obtained are but rough approximations. The drop method is not well fitted for accurate determinations, and the same may be said of the contact plate method which has been employed, amongst others by Schall, for similar purposes. The ring method used by Duprè and Wilhelmi has been taken up by Prof. Yamagawa of the Imperial University, who has given an expression by which the error due to hydrostatic pressure may be eliminated, and which has been applied to the measurement of surface tensions of various liquids. Timbéry\* has used a thin platinum ring to investigate the influence of temperature on capillary constants. He gives only one determination by this method for each temperature, while he takes the average of several measurements by Quincke's method. He says that the result obtained by the former method is so accurate and certain that no second determination is required to confirm it. This is an excellent account, and my own experience

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\* Wiedemann's Annalen 30 (1887) s.545.

fully corroborates it. When a ring with a very thin edge is used, the configuration for maximum surface-tension is most probably attained when  $i = 0$ , so that the correction for the contact angle is not required. I have tested a few liquids by this method with a very thin circular platinum ring, and have obtained the following results :

	Traction on the Ring		Capillary Height $\times$ Specific Gravity		Contact Angle Temperature $27^{\circ}-28^{\circ}$ .
	in grammes.	Water- 1.000.	No. of thermometer Grade $\times$ Sp. Gr.	Water- 1.000.	
Water	1.668	1.000	136.8	1.000	Supposed to be zero.
Alcohol	.526	.315	42.5	.311	..
Chloroform	.6215	.373	48.4	.357	$18^{\circ}$
Benzene	.6535	.392	45.1	.395	Supposed to be zero.

These are but rough determinations, the substances used being only tolerably pure : still the difference between the results obtained by the tube method and by the ring method is very significant. The capillary tube used in these experiments was a broken thermometer of a good bore, which showed no difference in the length of a mercury thread about the places used for the measurements. As the bore is very small (about  $\frac{1}{4}$  of a millimetre), no correction has been made for the meniscus. The ring had a perimetre of 69.8 m.m., and as it was very thin no correction has been made for hydrostatic pressure. The contact angle of benzene seems to be zero, while that of chloroform is rather large. It seems, therefore, advisable to use this method of measuring surface tension. As air is said to have considerable influence in depressing the capillary height in the case of water, it is desirable to conduct the experiment in vacuum, and as organic liquids dissolve gases with greater readiness than water does, the error

from this source may be considerable.\* The second series of Schiff's experiments is reported to be free from this source of inaccuracy.

Another consideration which tends to diminish the value of the formulæ is the temperature of comparison. The choice of the boiling points seems to be rather arbitrary, the pressure of vapor chosen depending entirely on the accident of our habitation. The theories of Van der Waal may perhaps give some aid in determining the temperature of comparison, but it is also probable that it will not furnish very accurate guidance. The only way to do this properly is to investigate the influence of temperature on capillary phenomena by a thoroughly reliable method, to see whether it has any relation to the changes of density of the liquid and pressure of the vapor and other concomitant phenomena.

All these considerations take away much of the apparent value of Schiff's formula as well as of those proposed in this paper, and call for a new and accurate investigation of the phenomena. The physical properties of all substances must chiefly depend on the chemical composition, and the science of chemistry must be regarded as being grievously backward, so long as she cannot predict these properties from the knowledge of the chemical constitution.

In conclusion I have to return my best thanks to Professor J. Sakurai, for the great interest which he has taken in my work and for his valuable suggestions.



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\* But this inaccuracy may be disguised by the smallness of the capillary constants in organic liquids.

# Determination of the Elements of the Sun's Spin.

by

S. Hirayama. *Rigakushi.*

Since the discovery of sun-spots by Fabricius and Galileo, the elements of the rotation of the sun, that is, the position of the sun's axis and its period of rotation, have been determined by many astronomers. These results are tabulated in Houzeau's *Vade-Mecum de l'Astronomie* (1), and differ greatly with the different observers. The various values of the inclination of the sun's equator to the ecliptic lie between  $6^{\circ}\frac{1}{2}$  and  $8^{\circ}$ , and those of the longitude of the node between  $60^{\circ}$  and  $80^{\circ}$ . The two most reliable results were obtained by Mr. Carrington and Dr. Spörer respectively, more than twenty years ago. Recently Dr. Wilsing has determined the elements from the periods of rotation of a single spot. If  $I$  is the inclination of the equator of the sun to the ecliptic, and  $N$ , the longitude of the ascending node, the results obtained by these three authorities are as follows:—

Authorities.	$N$	$I$	Epoch.
Carrington <sup>(2)</sup> .	$75^{\circ}40'$	$7^{\circ}15'$	1850
Spörer <sup>(3)</sup> .	$74^{\circ}52.3$	$6^{\circ}58'$	1861
Wilsing <sup>(4)</sup> .	$75^{\circ}78$	$7.16$	1882.0

(1) Houzeau, *Vade-Mecum de l'Astronomie*, § 162 Rotation pp. 411.

(2) Carrington, *Observations of the spots on the sun from 1853 to 1854* pp. 214.

(3) Spörer, *Beobachtungen der Sonnenflecken zu Anklam* (1874).

(4) Wilsing, *Neue Bestimmung der Rotations-elemente der Sonne* 1884. *Astr. Nach.* 31.



Then considering the nearly right angled triangle  $PQL'$ , we have

$$\begin{aligned}\delta' - \delta &= PL'Q - PP' \cos (PL'N + N'P'S) \\ &= PP' \cos PP'N \cos \alpha' - PP' \sin PP'N \sin \alpha' \\ \therefore \delta' - \delta &= X \cos \alpha' - Y \sin \alpha'\end{aligned}$$

if we assume

$$X = PP' \cos PP'N, \quad Y = PP' \sin PP'N.$$

If  $X$  and  $Y$  can be found from a series, or from many combined series of observations, then

$$PP' = \sqrt{X^2 + Y^2}, \quad \tan PP'N = \frac{Y}{X}.$$

But

$$\begin{aligned}X &= PP' \cos PP'N = PR - (N - N') \sin I \\ Y &= PP' \sin PP'N = P'R - I - I'\end{aligned}$$

Hence we have the following formulæ giving the true elements

$$\begin{aligned}I &= I' + Y \\ N &= N' + P, \operatorname{cosec} I.\end{aligned}$$

The above treatment gives  $\delta' - \delta = X \cos \alpha' - Y \sin \alpha'$  as the equations of conditions to find  $X$  and  $Y$ . It is a tremendous piece of work to apply this equation to each individual set of observations of spots. Hence it is necessary to consider in what way these quantities  $X$  and  $Y$  can most advantageously be found from the whole accumulated mass of observations. Since each series of observations yields a certain number of observed values of  $\delta'$  corresponding to observed values of  $\alpha'$ , we may assume the following series of equations.

$$\begin{aligned}\delta'_a - \delta &= X \cos a - Y \sin a \\ \delta'_b - \delta &= X \cos b - Y \sin b \\ \delta'_c - \delta &= X \cos c - Y \sin c \\ &\dots\dots\dots \\ &\dots\dots\dots\end{aligned}$$

By successive subtractions, we get

$$\begin{aligned}\delta'_b - \delta'_a &= X (\cos b - \cos a) - Y (\sin b - \sin a) \\ \delta'_c - \delta'_b &= X (\cos c - \cos b) - Y (\sin c - \sin b) \\ &\dots\dots\dots\end{aligned}$$



as the equations of condition to determine  $X$  and  $Y$ ;  $a, b, c, \dots$  the computed longitudes of the spots from the assumed node being known. Also by interpolating other values of  $\delta'$  for previously selected values of  $\alpha'$  at equal intervals, we simplify the calculation exceedingly. I have found the variations of latitude per 10 degrees of longitude by simply dividing the variation of latitudes by the difference of longitude. For example, for the solar spot No. 44, which appeared in March 1882 (see page 282 of Publicationen des Astrophysikalischen Observatorium zu Potsdam Nr. 17) we find

$\alpha'$ .	$90^\circ - \delta$ .	Variations of $90^\circ - \delta$ per $10'$ of $\alpha'$ .
135	-0.32	- 5
150	-0.40	- 6
163	-0.48	+ 7
178	-0.36	- 2
192	-0.39	+ 1
206	-0.37	0
222	-0.37	-15
236	-0.58	-11
250	-0.75	- 4
264	-0.89	-10
277	-0.93	

Thus  $-0^\circ.05, -0^\circ.06, \dots$  are considered to be the variations of latitude between longitudes  $140^\circ$  and  $150^\circ, 150^\circ$  and  $160^\circ, \dots$  respectively. This method of approximation will be sufficient for the majority of the observations. Having found the variations of latitude per  $10^\circ$  of longitude, we then tabulate them in the following form.

No.	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	.....
44.....		-5	-6	+7	+7	+7	-2	+1	+1		.....

I shall not reproduce all the numerical values obtained in this way for the whole interval of nearly 24 years. As an example, I shall give the complete method of reduction for the year 1884. In discussing in this way Spörer's observations, I shall of course adhere to the numbering of the different groups he has given. Table I. contains the number of each Potsdam group and the variation of latitudes per  $10^\circ$  of longitude, the same result being represented in a somewhat altered form in Table II. on separate sheet.

**Table I.**  
1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
272	$42^\circ$	$+11.4$	$+25$	240 <sup>c</sup>	$-9.2$			137 <sup>c</sup>	$-17.4$		$-13$
	58	$+11.8$	$+29$	136	$-9.3$		0	152	$-17.6$		$-8$
	72	$+12.2$	$-6$	151	$-9.3$		$-8$	165	$-17.7$		
	88	$+12.1$		164	$-9.4$		$-6$	35a	99	$+10.7$	$+2$
16a	109	$+12.3$	$+8$	189	$-9.5$		$+4$	142	$+10.8$		$+26$
	122	$+12.4$	$+7$	193	$-9.45$		0	157	$+11.2$		
	179	$+12.8$		207	$-9.15$		$-2$	35b	97	$+9.8$	$-2$
28	132	$-8.4$	0	235	$-9.5$		$+10$	140	$+9.7$		$-20$
	147	$-8.4$	0	264	$-9.2$			155	$+9.4$		$-25$
	175	$-8.4$	$-24$	32a	109	$+6.05$	$-18$		167	$+9.1$	
	192	$-8.8$	$+14$		128	$+6.4$	$+21$	37	66	$+9.5$	$-16$
	206	$-8.6$	$-7$		142	$+6.7$	$+13$		119	$+8.8$	0
	221	$-8.7$			157	$+6.9$	0		124	$+8.8$	$-23$
(53)	84	$-9.1$	$+3$		170	$+6.9$	$+7$		137	$+8.5$	$-5$
	113	$-9.0$	0		198	$+7.1$	$-20$		195	$+8.2$	$-15$
	141	$-9.0$	$-7$		213	$+6.8$			208	$+8.0$	0
	155	$-9.1$	$+7$	33a	65	$-16.6$	0		224	$+8.0$	
	169	$-9.0$	0		89	$-16.6$	$-13$	40	75	$+12.9$	$+20$
	198	$-9.0$	$-20$		107	$-16.95$	$-21$		90	$+13.2$	0
	213	$-9.3$	$+4$		123	$-17.3$	$-7$		102	$+13.2$	$-4$

Table I.—*Continued.*

1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
	159°	+13.0			192°	+12.4	-14		143°	+ 7.8	+13
38	91	+13.8	+13		206	+12.2	-21		158	+ 8.0	+ 7
	105	+14.4	-25		234	+11.6			186	+ 8.2	+21
	117	+14.1	+ 2	47a	77	+ 8.2	- 6		200	+ 8.5	+ 7
	(175	+14.7			108	+ 8.0	- 7		242	+ 8.8	
	(174	+13.3	-15		122	+ 7.9	-13	58	93	- 6.4	+ 6
	(188	+14.5			137	+ 7.7	- 7		169	- 6.3	-14
	(188	+13.1	0		166	+ 7.5	-11		151	- 6.9	
	(203	+14.5			194	+ 7.2	-13	60	121	+12.6	+48
	(203	+13.1	+10		209	+ 7.0	0		162	+12.8	-16
	232	+14.1			223	+ 7.0			193	+12.3	- 9
41	97	-24.0	+14	17b	163	+ 8.0	-10		248	+11.8	
	111	-23.8	- 8		192	+ 8.3	-14	63	130	+10.7	- 7
	123	-23.9	0		206	+ 8.1			160	+10.5	- 2
	178	-23.9	0	49	88	- 9.7	- 8		218	+10.4	- 8
	192	-23.9	- 7		101	- 9.8	-20		230	+10.3	
	207	-24.0	-14		116	-10.1	0	66a	140	+10.6	- 8
	231	-24.4			145	-10.1	- 3		152	+10.5	- 2
64	110	-25.7	-27		174	-10.2	+ 7		195	+10.4	+15
	140	-26.5	+ 4		188	-10.1	0		209	+10.6	
	195	-26.3	13		262	-10.1		72	138	- 7.6	+ 8
	208	-26.5	- 9	55a	123	+14.9	+ 6		151	- 7.5	+ 5
	250	-26.9	- 8		139	+15.0	-35		194	- 7.3	+ 7
	263	-22.0			170	+13.9	-31		209	- 7.2	- 8
44	121	+11.8	0		186	+13.4	-32		222	- 7.3	0
	134	+11.8	+20		214	+12.3	+13		237	- 7.3	
	149	+12.1	+10		229	+12.5		73	95	-16.0	+ 2
	178	+12.4	0	56	113	+ 7.9	- 3		139	-15.9	- 8

**Table I.**—*Continued.*

1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
	152°	+16.0	— $\frac{7}{7}$	75 <i>b</i>	122°	+11.8	0		179°	+ 7.9	— 3
	196	+16.3	—19		165	+11.8	— 6		208	+ 7.8	
	212	+16.6	— 8		182	+11.7	0	107	137	+ 8.2	—20
	221	+16.7	10		193	+11.7			117	+ 8.4	0
	253	+17.0		75	117	+15.3	+ $\frac{7}{7}$		161	+ 8.4	0
98	133	+17.3	0		159	+15.6	—12		219	+ 8.4	—20
	118	+17.3	0		176	+15.4	0		231	+ 8.1	—36
	162	+17.3	11		188	+15.4	—13		262	+ 8.0	
	176	+17.5	— $\frac{7}{7}$		203	+15.0		87	119	— 7.6	21
	190	+17.4	29		202	+15.4			118	+ 8.3	11
	204	+17.0	—25		217	+15.4	+ $\frac{7}{7}$		177	+ 8.8	+ 1
	228	+16.1	17		216	+15.5			269	+ 8.7	
	233	+16.6	21		231	+15.0	+ $\frac{7}{7}$	112	152	+ 8.9	0
	247	+16.3			230	+15.4			165	+ 8.9	+ $\frac{7}{7}$
74 <i>b</i>	189	+12.5	+16	78	141	+13.0	0		180	+ 8.8	+ 2
	205	+11.0	0		152	+13.0	+15		208	+ 8.75	
	218	+11.0			168	+12.8	+	91 <i>a</i>	219	+ 8.9	+28
74 <i>c</i>	181	+12.4	— $\frac{7}{7}$		181	+12.8	— $\frac{7}{7}$		233	+ 8.5	—19
	196	+12.2	13		196	+12.9			249	+ 8.8	— $\frac{7}{7}$
	208	+12.35	10	79	116	+12.6	+ $\frac{7}{7}$		264	+ 8.9	—36
	223	+12.5	+ $\frac{7}{7}$		131	+12.7	+15		278	+ 9.4	—13
	237	+12.1	0		144	+12.9	+ $\frac{7}{7}$		293	+ 9.6	
	252	+12.4			159	+13.0	+23	93	141	+ 8.7	0
75 <i>d</i>	122	+13.6	— $\frac{7}{7}$		172	+13.3			155	+ 8.7	— $\frac{7}{7}$
	165	+13.3	+ 6	80	107	+ 7.6	— $\frac{7}{7}$		170	+ 8.8	+ $\frac{7}{7}$
	182	+13.4	— 8		122	+ 7.5	+15		184	+ 8.6	
	194	+13.3	—10		135	+ 7.7	+10		185	+ 8.7	—14
	223	+13.0			164	+ 8.0	— $\frac{7}{7}$		199	+ 8.9	— $\frac{7}{7}$

Table I.—*Continued.*

1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
	213°	— 9.0	— 7		221°	—12.8	0		289°	—13.8	0
	228	— 9.1	0		231	—12.8	0		303	—13.8	+ 7
	243	— 9.1	—15		246	—12.8	— 9		317	—13.7	— 6
	256	— 9.3	+13		289	—13.2	—15		333	—13.8	+ 7
	270	— 8.7	0		302	—13.4			348	—13.7	
	289	— 8.7		101	182	—19.6	—12	118a	219	— 9.3	—21
96b	222	—11.1	— 5		196	—20.1	—35		233	— 9.6	—29
	241	—11.2	—60		213	—20.7	—50		247	—10.0	—11
	251	—11.8	—15		223	—21.2	+ 7		278	—10.2	+ 8
	264	—12.0			237	—21.1			290	—10.1	—11
86c	220	—11.8	0	113a	155	— 9.9	+13		308	—10.3	
	238	—11.8	—55		171	— 9.7	+21	119b	225	—11.6	—21
	249	—12.1	+29		199	— 9.1	0		237	—11.89	— 5
	263	—12.0			273	— 9.1	—10		281	—15.1	— 1
97	145	—11.1	—21		313	— 9.5			309	—15.2	+ 7
	159	—11.1	—33	116	208	—13.5	—19		323	—15.1	
	174	—11.9	—21		219	—11.3	0	125a	251	+ 8.8	+13
	188	—15.2	+ 7		263	—11.3	—13		266	+ 9.0	0
	202	—15.1	+11		278	—11.5	—10		282	+ 9.0	0
	216	—11.9			309	—11.8	+36		295	+ 9.0	—13
98b	185	—19.2	+10		320	—11.4			310	+ 8.8	+ 7
	201	—18.6	+11	138	191	—11.6	+ 7		324	+ 8.9	
	220	—18.1	—20		205	—11.5	+19	125b	261	+ 7.5	— 7
	239	—18.6	—13		221	—11.2	0		289	+ 7.3	—11
	244	—19.2			233	—11.2	+11		303	+ 7.1	
99b	175	—12.4	0		247	—11.0	+14	127	177	+12.6	—17
	189	—12.4	0		261	—13.8	0		191	+12.3	+18
	203	—12.4	—22		275	—13.8	0		205	+12.5	+14

Table I.—*Continued.*

1884.

Spot	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
	219°	+12.7	— 7		319°	— 6.3	0		231°	— 2.0	—14
	231	+12.6	+ 7		333	— 6.3	0		245	— 2.2	—20
	249	+12.5			347	— 6.3	0		259	— 2.5	— 5
130 <i>a</i>	232	+ 7.7	—14		351	— 6.3	—18		279	— 2.6	— 9
	246	+ 7.5	— 7		2	— 6.5			290	— 2.7	+ 8
	250	+ 7.4		171	213	— 7.3	0		303	— 2.6	+ 7
139 <i>b</i>	250	+ 6.4	0		227	— 7.3	— 7		318	— 2.5	
	260	+ 6.4	— 7		241	— 7.4	0	149	188	— 9.2	—23
	275	+ 6.3			255	— 7.4	+ 7		201	— 9.5	+ 7
134	169	— 7.2	—17		269	— 7.3	—10		215	— 9.4	+ 7
	181	— 7.45	— 3		298	— 7.6	0		229	— 9.3	—14
	199	— 7.5	0		312	— 7.6	+ 7		243	— 9.5	0
	212	— 7.5	0		326	— 7.5	+29		257	— 9.5	— 7
	227	— 7.5	— 7		343	— 7.9	+18		271	— 9.6	0
	241	— 7.6	— 7		354	— 6.8	+ 7		285	— 9.6	+ 7
	255	— 7.7	— 4		8	— 6.7	+21		300	— 9.5	—14
	282	— 7.8	+ 7		22	— 6.4			314	— 9.7	+13
	296	— 7.7	—19	137	203	— 4.6	— 7		329	— 9.5	+15
	312	— 8.0	—15		217	— 4.7	0		342	— 9.3	
	325	— 8.2	—14		234	— 4.7	—23	159	196	— 8.0	— 7
	339	— 8.4	— 8		247	— 2.0	—21		210	— 8.1	— 5
	342	— 8.5			261	— 2.3	—29		229	— 8.2	0
152	192	— 7.5	+29		275	— 2.7	—20		249	— 8.2	0
	207	— 7.2	+13		290	— 3.0	—21		254	— 8.2	0
	222	— 7.0	+ 5		304	— 3.3	—14		269	— 8.2	+14
	292	— 6.7	+17		318	— 3.5	+13		343	— 8.0	— 9
	304	— 6.3	0		333	— 3.3			354	— 8.1	—14
	304	— 6.3	0	156	219	— 2.0	0		8	— 8.3	

Table I.—Continued.

1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
141	179°	+18.4	-23		260°	-15.6	+ 7	147	186°	-15.6	+14
	192	+18.1	0		274	-15.5	-14		200	-15.4	-24
	207	+18.1	0		288	-15.7	+20		217	-15.8	- 4
	220	+18.1	0		303	-15.4	-17		242	-15.9	+ 7
	234	+18.1	-13		320	-15.7	- 8		256	-15.8	0
	249	+17.9	-14		345	-15.9			270	-15.8	-12
	263	+17.7	-14	143a	186	-11.6	-20		287	-16.0	+13
	277	+17.5	-38		201	-11.9	-14		302	-15.8	
	290	+17.0	0		215	-12.0	0	146	192	+ 8.3	+14
	305	+17.0	+ 6		228	-12.0	+ 6		206	+ 8.5	-24
	322	+17.1			244	-11.9	0		223	+ 8.1	+ 4
142a	241	+14.8	- 6		258	-11.9	+ 7		249	+ 8.2	-14
	257	+14.1	+31		273	-11.8	-15		263	+ 8.0	- 7
	273	+14.6	0		285	-12.0	- 7		277	+ 7.9	0
	286	+14.6	-13		301	-12.1	-12		293	+ 7.9	-13
	301	+14.4	0		318	-12.3	0		308	+ 7.7	
	318	+14.4	-14		344	-12.3		166	215	+ 9.3	-20
	344	+14.0		144a	179	-24.1	-40		230	+ 9.0	-25
142b	237	+15.7	0		194	-24.7	+31		246	+ 8.6	-17
	250	+15.7	+27		207	-24.3	0		258	+ 8.4	
	265	+16.1	+ 8		221	-24.3	-25		277	+ 8.2	0
	278	+16.2	0		237	-24.7			285	+ 8.2	-13
	293	+16.2		144b	184	-24.3	+14		301	+ 8.0	0
143	188	-15.2	-20		198	-24.1	+ 8		316	+ 8.0	+ 8
	203	-15.5	+ 7		211	-24.0	-20		329	+ 8.1	+ 7
	217	-15.4	+ 7		226	-24.3	+ 8		343	+ 8.2	
	231	-15.3	-20		239	-24.2	+ 7	148a	189	-15.7	- 6
	246	-15.6	0		254	-24.1			207	-15.8	+ 4

**Table I.**—*Continued.*

1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
	233 <sup>c</sup>	-15.7	0	251	+ 9.7	$\pm$ 0		314 <sup>c</sup>	+13.0		
	247	-15.7	- 7	273	+ 9.7	-13	173	219	+ 8.1	- 8	
	262	-15.8	0	289	+ 9.5	-23		231	+ 8.0	+13	
	278	-15.8	0	302	+ 9.2			246	+ 8.2	- 8	
	293	-15.8		165	213	-12.3	-19	259	+ 8.1	0	
155a	297	+ 9.7	- 8	229	-12.6	-13		288	+ 8.1	0	
	310	+ 9.6	- 6	245	-12.8	+17		302	+ 8.1		
	326	+ 9.5		257	-12.6	-11	174a	339	+10.8	+13	
155b	282	+11.3	0	276	-12.8	-33		351	+11.0	+50	
	293	+11.3	-19	285	-13.1	+ 7		8	+11.7	- 7	
	309	+11.0		300	-13.0	-13		23	+11.6		
157	216	+ 6.5	+ 9	315	-13.2	- 8	171	211	+10.4	-14	
	227	+ 6.6	-13	328	-13.3	- 6		258	+10.2	+19	
	242	+ 6.4	-20	341	-13.4	-17		271	+10.5	0	
	257	+ 6.4	0	356	-13.6			283	+10.5		
	275	- 6.1	-27	165b	222	-13.5	12	176	235	+ 8.0	+17
	283	+ 5.8	14	239	-13.7	-12		247	+ 8.2	+ 7	
	300	+ 5.6	+13	251	-14.2	0		262	+ 8.3	- 7	
	315	+ 5.8		270	-14.2	-22		277	+ 8.2	-13	
160b	201	+14.3	+ 7	279	-14.4			292	+ 8.0	0	
	215	+14.4	0	168a	227	+12.1	-14	306	+ 8.0	+53	
	231	+14.4		241	+11.9	+21		321	+ 8.8		
164	333	+ 9.2	+28	260	+12.3	0	177	235	- 5.8	-20	
	347	+ 9.6	+13	270	+12.3	-18		259	- 6.1	-11	
	1	+10.2	+13	287	+12.0	+53		268	- 6.3	-18	
	16	+10.4		302	+12.8	+ 7		279	- 6.5	-11	
180	232	+10.2	- 7	316	+12.9	- 7		293	- 6.7	+13	
	247	+10.4	-29	331	+12.8	+15		308	- 6.5	-15	



Table I.—*Continued.*

1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
	321°	— 6.7	+12		324°	+ 5.2	— 8		343°	+ 4.8	+ 7
	338	— 6.5	—33		336	+ 5.1	—14		357	+ 4.9	—14
	350	— 6.9	—13		350	+ 4.9	—13		11	+ 4.7	
	5	— 7.1	—13		6	+ 5.1		194d	313	+ 6.7	+20
	20	— 7.3	+21	188a	281	+ 3.2	— 6		328	+ 7.0	—23
	31	— 7.0			316	+ 3.9	—11		341	+ 6.7	+31
178a	300	— 2.7	—11		334	+ 2.8	—25		354	+ 7.1	—36
	314	— 2.9	+12		346	+ 2.5	—29		8	+ 6.6	+39
	331	— 2.7	—11		360	+ 2.1	0		26	+ 7.3	+ 4
	345	— 2.9	—20		16	+ 2.1	0		52	+ 7.1	
	360	— 3.2	—13		15	+ 2.1		196	253	— 6.4	— 7
	16	— 3.4	+14	188b	277	+ 3.9	— 7		268	— 6.5	— 7
	30	— 3.2			305	+ 3.7	—11		282	— 6.6	—18
199	264	— 3.0	8		323	+ 3.5	0		299	— 6.9	—15
	290	— 3.2	— 6		335	+ 3.5	—29		312	— 7.1	
	307	— 3.1	0		349	+ 3.1	— 6	197	354	— 5.9	0
	317	— 3.1	+ 7		5	+ 3.0	+11		270	— 5.9	+ 8
	331	— 3.0	+ 7		33	+ 3.3			282	— 5.8	—14
	346	— 3.1	0	194a	317	+ 4.8	+33		296	— 6.0	+14
	3	— 3.1	— 9		335	+ 5.4	—29		310	— 5.8	— 5
	14	— 3.2	+ 7		349	+ 5.0	+46		329	— 5.9	+ 5
	29	— 3.1	+ 7		2	+ 5.6			351	— 5.8	0
	43	— 3.0	+ 7	194a'	18	+ 5.2	— 6		12	— 5.8	+10
	57	— 2.9			36	+ 5.1	+12		22	— 5.7	— 7
186a	355	—11.8	+ 7		62	+ 5.1			36	— 5.8	+ 7
	9	—11.7	+18	194c	299	+ 5.2	— 7		51	— 5.7	0
	26	—11.4			314	+ 5.1	0		66	— 5.7	
188c	307	+ 4.9	+18		330	+ 5.1	—23	203	321	+ 3.5	+13

Table I.—*Continued.*

1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
	336°	+ 3.7	+ 11		52°	+ 17.3	+ 6	229	213°	— 3.9	+ 19
	350	+ 3.9	+ 8		68	+ 17.4	+ 58		329	— 3.6	— 11
	3	+ 4.0			80	+ 18.1			357	— 3.9	
207b	11	+ 11.8	+ 21	217	336	— 22.9	+ 12	223	290	+ 4.7	+ 6
	25	+ 11.5	+ 13		2	— 23.2	+ 8		307	+ 4.8	— 18
	40	+ 11.7	0		15	— 23.3	15		318	+ 4.6	— 15
	56	+ 11.7			28	— 23.5	+ 18		331	+ 4.4	0
207a	333	+ 15.0	+ 5		45	— 23.2	+ 30		347	+ 4.4	— 14
	46	+ 15.2	+ 21		55	— 22.9	+ 7		4	+ 4.2	+ 7
	39	+ 14.9	+ 20		69	— 23.0	+ 21		16	+ 4.3	14
	45	+ 15.2	20		83	— 22.7			58	+ 3.7	— 6
	60	+ 14.9	+ 7	219a	352	+ 13.4	+ 25		75	+ 3.6	
	74	+ 15.0			42	+ 13.9	+ 8	228a	329	— 8.0	+ 25
285	+ 14.6	+ 7			24	+ 13.8	14		349	— 7.5	+ 32
299	+ 14.7	13			42	+ 13.0	17		17	— 6.6	0
314	+ 14.5	4			54	+ 12.8	+ 7		34	— 6.6	+ 12
359	+ 14.3	0			68	+ 12.9	+ 13		51	— 6.4	12
	43	+ 14.3	+ 19		83	+ 13.1	+ 14		63	— 6.9	— 15
	39	+ 14.8	+ 19		97	+ 13.3			90	— 7.3	+ 7
	55	+ 15.1	+ 13	222a	289	+ 5.1	0		105	— 7.4	
	74	+ 15.3	0		316	+ 5.1	0	229	313	— 3.9	+ 19
	83	+ 15.3			332	+ 5.1	+ 4		329	— 3.6	— 14
227b	282	+ 16.2	+ 7		0	+ 5.6	0		357	— 3.9	
	296	+ 16.3	0		11	+ 5.0	— 14	230	307	— 12.8	— 13
	311	+ 16.3	+ 5		25	+ 4.8	+ 7		322	— 13.0	— 29
	353	+ 16.5	+ 6		40	+ 4.9	+ 7		339	— 13.5	0
	40	+ 16.6	+ 15		54	+ 4.8	0		351	— 13.5	— 14
	36	+ 17.0	+ 19		68	+ 4.8			48	— 13.8	0

Table I.—*Continued.*

1884.

Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.	Spot.	$\alpha'$	Lat.	Diff.
	32°	−13.8	+ 7	262a	33°	+ 7.6	0		94°	+ 3.3	+ 7
	46	−13.7	−13		62	+ 7.6	−17		108	+ 3.4	− 7
	61	−13.9	− 9		92	+ 7.1	− 2		123	+ 3.3	+ 7
	105	−11.3			135	+ 7.0			138	+ 3.4	+30
231a	340	−13.8	+ 7	262b	60	+ 8.1	+ 6		148	+ 3.7	
	10	−13.6	+13		91	+ 8.3	+ 2	269	19	− 6.3	− 3
	26	−13.4	0		133	+ 8.1			18	− 6.4	+ 7
	41	−13.4	− 7	265a	92	−15.1	+ 7		62	− 6.3	0
	56	−13.5	+11		106	−15.0	+ 8		77	− 6.3	0
	100	−12.9			119	−14.9	+ 6		91	− 6.3	
238 $\alpha$	4	+11.8	0		136	−14.8	0	270	13	+ 4.1	−13
	18	+14.8	+ 6		149	−14.8			28	+ 4.2	+ 7
	49	+15.0	− 4	266	43	+15.1	−18		42	+ 4.3	0
	77	+14.9	0		60	+11.8	−17		54	+ 4.3	+16
	88	+14.9			75	+14.1	+20		97	+ 5.0	
238 $\beta$	17	+14.3	−16		90	+14.1	−21	274	24	−12.5	+13
	48	+13.8	+18		119	+13.8	+ 7		55	−12.1	+ 6
	76	+14.3	0		134	+13.9	+33		87	−11.9	+ 6
	87	+14.3			149	+14.1			118	−11.7	+12
253a	1	+ 9.6	+13	266b	41	+13.4	−53		135	−11.5	
	17	+ 9.8	+ 8		56	+12.6	−50	263	74	− 6.8	− 7
	30	+ 9.9	+11		70	+11.9	+ 7		117	− 7.1	0
	44	+10.1	+14		85	+12.0	+10		160	− 7.1	
	58	+10.3	+36		114	+12.3	+12	277	56	− 7.0	+ 5
	72	+10.8	+13		128	+12.9	−13		113	− 6.7	+ 8
	102	+11.2	+19		143	+12.7	− 6		184	− 6.1	
	118	+11.5	+ 8		159	+12.6					
	130	+11.6		268	65	+ 3.1	− 3				

Table II. gives, as final results, the total sums of the variations of latitude per 10 degrees of longitude and the corresponding total number in the year 1884. In like manner, similar sums were obtained for each year from 1861 to 1884. The results of the whole are tabulated in Table III.

In the last three rows of Table III., the results of 24 years are given, the last row giving the mean value of the variation of latitudes per 10 degrees of longitude. Supposing the weight of each column to be proportional to the total number in the corresponding column, multiply each of these mean values by its weight. Sum the whole, and divide by the sum of the weights. There results a mean excess of  $-0^{\circ}.00217$ , which would imply that on the whole there is an average tendency toward the equator of nearly  $8''$  in the time during which the sun rotates through  $16^{\circ}$ . But considering the approximate character of the method of reduction and the probable effects of the errors of observations, we are, I think, justified in altogether neglecting this result.

To annihilate this equal departure on either side of zero, I have deducted this quantity  $-0^{\circ}.002$  from the mean values in each column.

So that we have finally the following data to find  $X$  and  $Y$ .

	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Differences, .....	+ 1.1	+ 2.1	+ 3.7	+ 4.0	+ 4.5	+ 3.5	+ 3.1	+ 4.6	+ 2.8	
Weight, .....	272	261	245	238	236	223	208	201	196	

	90°	100°	110°	120°	130°	140°	150°	160°	170°	180°
Differences, .....	+ 2.2	+ 2.1	- 0.6	- 0.2	+ 3.1	+ 3.7	+ 0.5	- 1.1	+ 0.9	
Weight, .....	182	180	176	187	195	197	203	223	231	

	180°	190°	200°	210°	220°	230°	240°	250°	260°	270°
Differences. ....	- 1.2	- 0.3	- 1.0	- 1.1	- 0.2	- 1.1	- 2.5	- 3.2	- 2.5	
Weight. ....	256	276	286	294	308	316	318	317	304	

	270°	280°	290°	300°	310°	320°	330°	340°	350°	360°
Differences. ....	- 6.2	- 4.8	- 3.2	- 2.1	- 0.9	- 1.6	- 1.2	+ 1.3	+ 2.0	
Weight. ....	305	291	292	286	281	282	278	281	281	

From these we get the following 36 equations of condition,

$$\begin{aligned}
 & (-015 X - 174 Y + 14 = 0) \times 2.72 & (+015 X + 174 Y - 12 = 0) \times 2.56 \\
 & (-015 X - 168 Y + 24 = 0) \times 2.61 & (+015 X + 168 Y - 3 = 0) \times 2.76 \\
 & (-074 X - 158 Y + 37 = 0) \times 2.15 & (+074 X + 158 Y - 10 = 0) \times 2.86 \\
 & (-100 X - 143 Y + 40 = 0) \times 2.38 & (+100 X + 143 Y - 11 = 0) \times 2.94 \\
 & (-123 X - 123 Y + 45 = 0) \times 2.35 & (+123 X + 123 Y - 2 = 0) \times 3.08 \\
 & (-143 X - 100 Y + 35 = 0) \times 2.23 & (+143 X + 100 Y - 14 = 0) \times 3.16 \\
 & (-158 X - 074 Y + 31 = 0) \times 2.08 & (+158 X + 074 Y - 25 = 0) \times 3.18 \\
 & (-168 X - 045 Y + 46 = 0) \times 2.01 & (+168 X + 045 Y - 32 = 0) \times 3.17 \\
 & (-174 X - 015 Y + 28 = 0) \times 1.99 & (+174 X + 015 Y - 25 = 0) \times 3.04 \\
 & (-174 X + 015 Y + 22 = 0) \times 1.82 & (+174 X - 015 Y - 62 = 0) \times 3.05 \\
 & (-168 X + 045 Y + 21 = 0) \times 1.89 & (+168 X + 045 Y - 48 = 0) \times 2.91 \\
 & (-158 X + 074 Y - 6 = 0) \times 1.76 & (+158 X + 074 Y - 32 = 0) \times 2.92 \\
 & (-143 X + 100 Y - 2 = 0) \times 1.87 & (+143 X + 100 Y - 21 = 0) \times 2.86 \\
 & (-123 X + 123 Y + 31 = 0) \times 1.95 & (+123 X + 123 Y - 9 = 0) \times 2.84 \\
 & (-100 X + 143 Y + 37 = 0) \times 1.97 & (+100 X + 143 Y - 16 = 0) \times 2.82 \\
 & (-074 X + 158 Y + 5 = 0) \times 2.03 & (+074 X + 158 Y - 12 = 0) \times 2.78 \\
 & (-045 X + 168 Y - 14 = 0) \times 2.23 & (+045 X + 168 Y + 13 = 0) \times 2.84 \\
 & (-015 X + 174 Y + 9 = 0) \times 2.31 & (+015 X + 174 Y + 20 = 0) \times 3.81
 \end{aligned}$$

The solution of these 36 equations by means of the least squares gives

$$X = +0^{\circ}.18951 \quad Y = +0^{\circ}.93842$$

Hence

$$\delta' - \delta = +0^{\circ}.185 \cos (\alpha + 12^{\circ}.0)$$

Table I



Table III.





Also

$$\left. \begin{aligned} I + I' + Y &= 6^{\circ}.968 + 0^{\circ}.038 = 6^{\circ}.996 = 7^{\circ}.006 \\ N + N' + X \operatorname{cosec} I &= 74^{\circ}.523 + 1^{\circ}.480 = 76^{\circ}.003 \end{aligned} \right\} \text{for 1861}$$

Here we see that the value of the node is larger than any of the values given at the beginning of the paper. The value of the inclination is nearly the same as that given by Spörer.

As a check on this result, I calculated the variations of latitudes at equal intervals of  $30^{\circ}$  degrees of longitude, by summing the three successive columns of the Table III. and dividing the results by the average number of spot occurrences. Also to see if there is a noticeable secular change in both node and inclination, I divided the interval of 24 years into three separate periods : first, from 1861 to 1868 ; second, from 1869 to 1879 ; third, from 1880 to 1884. Separate reductions were made for these three distinct periods. The resulting differences of latitude and the number of spots are shown in Table IV.

Table IV.

		$0^{\circ}$	$30^{\circ}$	$60^{\circ}$	$90^{\circ}$	$120^{\circ}$	$150^{\circ}$	$180^{\circ}$	$210^{\circ}$	$240^{\circ}$	$270^{\circ}$	$300^{\circ}$	$330^{\circ}$	$360^{\circ}$
(A)	1861...1868	(Diff.)	+ 248	+ 383	+ 406	+ 75	+ 78	+ 85	- 326	- 151	- 485	- 424	- 30	+ 560
		(Nos.)	46	12	39	31	28	37	54	56	57	53	50	48
		(Means)	+ 5.4	+ 9.1	+ 10.4	+ 2.1	+ 2.8	+ 2.3	- 6.0	- 2.7	- 8.5	- 8.0	- 6.9	+ 11.7
			+ 4.6	+ 8.3	+ 9.6	+ 1.6	+ 2.0	+ 1.5	- 6.8	- 3.5	- 9.3	- 8.8	- 1.4	+ 10.9
(B)	1869...1879	(Diff.)	+ 971	+ 1147	+ 989	+ 244	+ 17	- 521	- 287	- 560	- 1336	- 2194	- 766	+ 61
		(Nos.)	8	76	63	61	67	78	95	116	124	116	101	95
		(Means)	+ 10.5	+ 15.1	+ 15.7	+ 4.0	+ 0.3	- 6.7	- 3.0	- 4.8	- 10.8	- 18.9	- 7.6	+ 0.6
			+ 13.0	+ 17.2	+ 17.8	+ 6.1	+ 2.4	- 4.6	- 0.9	- 2.7	- 8.7	- 16.8	- 5.5	+ 2.7
(C)	1880...1884	(Diff.)	+ 542	+ 1115	+ 594	+ 246	+ 1082	+ 307	- 232	- 295	- 913	- 1747	- 677	- 183
		(Nos.)	125	115	98	88	97	104	124	134	131	127	133	138
		(Means)	+ 4.3	+ 9.8	+ 6.1	+ 2.8	+ 11.2	+ 3.0	- 1.9	- 2.2	- 7.6	- 13.8	- 5.1	- 1.3
			+ 4.4	+ 9.9	+ 6.2	+ 2.9	+ 11.3	+ 3.1	- 1.8	- 2.1	- 6.9	- 13.7	- 5.0	- 1.2
(D)	1861...1884	(Diff.)	+ 1761	+ 2647	+ 1989	+ 565	+ 1177	- 129	- 815	- 1006	- 2734	- 4365	- 1473	+ 438
		(Nos.)	259	232	200	175	193	220	273	206	313	296	281	281
		(Means)	+ 6.8	+ 11.4	+ 9.9	+ 3.2	+ 6.1	- 0.6	- 3.1	- 3.3	- 8.7	- 14.7	- 5.2	+ 1.6
			+ 7.5	+ 12.1	+ 10.6	+ 3.5	+ 6.8	+ 0.1	- 2.4	- 2.6	- 8.0	- 14.0	- 1.5	+ 2.3

Table IV, gives the following four sets of equations of conditions deduced respectively from  $A$ ,  $B$ ,  $C$ , and  $D$ , of that table. These four sets of equations I shall call  $A'$ ,  $B'$ ,  $C'$ , and  $D'$  respectively.

 $A'$ 

$(-134 \ X-500 \ Y+46=0)$	1.15
$(-366 \ X-366 \ Y+83=0)$	1.05
$(-500 \ X-134 \ Y+95=0)$	0.98
$(-500 \ X+134 \ Y+16=0)$	0.78
$(-366 \ X+366 \ Y+20=0)$	0.70
$(-134 \ X+500 \ Y+15=0)$	0.93
$(+134 \ X+500 \ Y-68=0)$	1.35
$(+366 \ X+366 \ Y-35=0)$	1.40
$(+500 \ X+134 \ Y-93=0)$	1.43
$(+500 \ X-134 \ Y-88=0)$	1.33
$(+366 \ X-366 \ Y-14=0)$	1.25
$(+134 \ X-500 \ Y+109=0)$	1.20

 $C'$ 

$(-134 \ X-500 \ Y+44=0)$	1.25
$(-366 \ X-366 \ Y+99=0)$	1.14
$(-500 \ X-134 \ Y+62=0)$	.98
$(-500 \ X+134 \ Y+29=0)$	.88
$(-366 \ X+366 \ Y+113=0)$	.97
$(-134 \ X+500 \ Y+31=0)$	1.04
$(+134 \ X+500 \ Y-18=0)$	1.24
$(+366 \ X+366 \ Y+21=0)$	1.34
$(+500 \ X+134 \ Y-69=0)$	1.31
$(+500 \ X-134 \ Y-137=0)$	1.27
$(+366 \ X-366 \ Y-50=0)$	1.33
$(+134 \ X-500 \ Y-12=0)$	1.38

 $B'$ 

$(-134 \ X-500 \ Y+130=0)$	1.11
$(-366 \ X-366 \ Y+172=0)$	0.95
$(-500 \ X-134 \ Y+178=0)$	0.79
$(-500 \ X+134 \ Y+64=0)$	0.76
$(-366 \ X+366 \ Y+24=0)$	0.84
$(-134 \ X+500 \ Y-46=0)$	0.88
$(+134 \ X+500 \ Y-9=0)$	1.19
$(+366 \ X+366 \ Y-27=0)$	1.45
$(+500 \ X+134 \ Y-87=0)$	1.55
$(+500 \ X-134 \ Y-168=0)$	1.45
$(+366 \ X-366 \ Y-55=0)$	1.26
$(+134 \ X-500 \ Y+27=0)$	1.19

 $D'$ 

$(-134 \ X-500 \ Y+75=0)$	1.30
$(-366 \ X-366 \ Y+121=0)$	1.16
$(-500 \ X-134 \ Y+106=0)$	1.00
$(-500 \ X+134 \ Y+39=0)$	0.90
$(-366 \ X+366 \ Y+68=0)$	0.97
$(-134 \ X+500 \ Y+1=0)$	1.10
$(+134 \ X+500 \ Y-24=0)$	1.37
$(+366 \ X+366 \ Y-26=0)$	1.53
$(+500 \ X+134 \ Y-80=0)$	1.57
$(+500 \ X-134 \ Y-110=0)$	1.48
$(+366 \ X-366 \ Y-45=0)$	1.42
$(+134 \ X-500 \ Y+23=0)$	1.41

The set of equations ( $A'$ ) gives

$$X = +0^{\circ}.1323 \quad Y = +0^{\circ}.077$$

„ „ „ „ ( $B'$ ) „

$$X = +0^{\circ}.2134 \quad Y = +0^{\circ}.060$$

„ „ „ „ ( $C'$ ) „

$$X = +0^{\circ}.1692 \quad Y = +0^{\circ}.004$$

„ „ „ „ ( $D'$ ) „

$$X = +0^{\circ}.1792 \quad Y = +0^{\circ}.038$$

These give the following results :—

from $A'$	$N = 75^{\circ}.692$	$I = 7^{\circ}.945$
„ $B'$	$N = 76^{\circ}.379$	$I = 7^{\circ}.028$
„ $C'$	$N = 76^{\circ}.184$	$I = 6^{\circ}.964$
„ $D'$	$N = 75^{\circ}.992$	$I = 7^{\circ}.006$

It should be noticed that the values of the ascending node obtained from  $D'$  serves to check the previous determination. The difference amounts to almost forty seconds of arc which I do not consider too much for this kind of determination. A comparison of the values deduced from  $A'$ ,  $B'$ , and  $C'$ , seems to hint at a certain increase in the values of node in time. This was assumed by Spörer, but I do not insist on this point firmly. I also here notice that in his reduction of spot observations, Spörer has since 1880 applied a correction for refraction due to the sun's atmosphere ; so that the heliographic latitudes deduced are somewhat different. I have, however, used the deduced values of longitudes and latitudes without alteration, throughout the long series of 24 years.

The principal conclusion to be drawn from the present calculations is that the values of the ascending node of the sun's equator given by Carrington and Spörer are distinctly smaller than the values now deduced. Wilsing's values, however, resembles mine pretty closely. Finally I venture to propose the following elements for 1861.

$$\begin{array}{l} I = 7^{\circ}.906 ) \\ N = 76^{\circ}.993 ) \end{array} \quad \text{for 1861}$$

In conclusion I desire to acknowledge my indebtedness to Prof. Terao, Director of the Tōkyō Astronomical Observatory for his kind and valuable suggestions.





# On the Fineness of the One Yen Silver Coin.

by

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and

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## 1. Introduction.

The experiments recorded in the following pages have for their object the study of the nature of segregation of silver in the one yen coin, and of the mode of taking portions for assay from the coin in such a manner that portions so taken shall represent the exact composition of the whole piece.

The subject is of considerable importance in the technical operations of the mint, and also with regard to the provisions of the law which governs the issue of national coinage.

It is comparatively easy to determine with exactness the average fineness of a mass of silver coins, for they may be melted together in a crucible, and a small portion dipped out of the melted mass after a thorough stirring may then be granulated in water. The granules thus obtained will exactly represent the average composition of the mass, provided that the coins have been melted in sufficient quantity and with certain precautions in order to prevent oxidation in the process of fusion.

The exact determination of the fineness of any individual coin is not so easy, since the silver-copper alloy usually employed in coinage shows the property of segregation to a considerable degree, the silver being concentrated towards the centre of the ingot made from this alloy. A small portion cut from the coin in a haphazard manner will not therefore be the true representative sample of the coin taken as a whole.

Although the experiments strictly refer to the silver yen coin, yet the conclusions drawn from them may be applied equally well to many other coins, when the conditions of manufacture are similar.

In order to obtain a clear understanding of such conditions, it may be perhaps useful to give a brief account of the process of silver minting in the Imperial Mint.

The process of minting begins with the melting of refined silver with the right proportion of copper in a crucible, the metal being covered with a layer of powdered charcoal. When in perfect fusion, the bath is stirred up thoroughly; a small portion is dipped out and immediately let fall into cold water. The small shots, or granules of the alloy thus obtained are dried and reserved for assay, which determines the exact proportion of silver in that melt. The metal is then poured into cast iron moulds and transformed into long flat strips or "bars," which are taken out of the moulds and cooled in water. The bars are next rolled out by a pair of rollers, until they are reduced to the thickness of the coin to be manufactured. In the course of lamination, these bars, now known as "fillets," usually require to be annealed, an operation which is performed in a sort of reverberatory furnace, where they are heated to a low redness; they are then taken out and immediately cooled in water, so as to reduce the oxidation of the metal to a minimum.

The finished fillets are taken to the cutting machine, by which

circular discs or “ blanks ” are punched out of them. A single row of blanks are cut from each fillet in the case of large coins, such as the silver yen. The blanks are next adjusted in weight, usually by means of an automaton balance.

After being “ marked ” or compressed on the edges, they are annealed in iron pans, introduced into a furnace similar to that just mentioned. When taken out they are cooled in water and washed in very dilute sulphuric acid, by which the superficial layer of copper oxide is dissolved out, leaving the blanks with a clean white surface. After washing and drying, the blanks are ready for the coining press, where they are transformed into coins. Finally the coins thus prepared must be tested as to the sound, and the correctness of weight and fineness, before they are allowed to be issued to the public.

The dimensions of the silver yen coinage bar and of the finished fillet are :

	Bar.	Fillet
Length.	60.00 cm	
Breadth.	4.30 „	5.00 cm
Thickness.	1.25 „	0.23 „

The dimensions, &c., of blank and coin are :

	One Yen Blank.	One Yen Coin.
Diameter. ....	38.0 mm	38 mm
Thickness. ....	2.3 mm	—
Legal weight. ....		416 grains, (26.957 Gram.).
Legal tolerance in weight. ... ..		1.5 „ above or below legal weight.
Legal fineness. ....		900 per mille.
Legal tolerance in fineness. ....		2.0 above or below 900.

It will be seen from the preceeding account, that many other



causes than mere segregation of silver have more or less influence on the actual fineness of the finished coin, for some stages of the process tend to lower the fineness by the oxidation of the metal, while other stages act in an opposite way by taking away a part of the oxide formed.

## II. Distribution of Silver on the Coin.

The first series of experiments consisted in the endeavour to discover the average fineness of the One Yen coin produced from bars, of which the assay of granulation was known, and to examine extent the of segregation by which different portions of the same coin differed in composition.

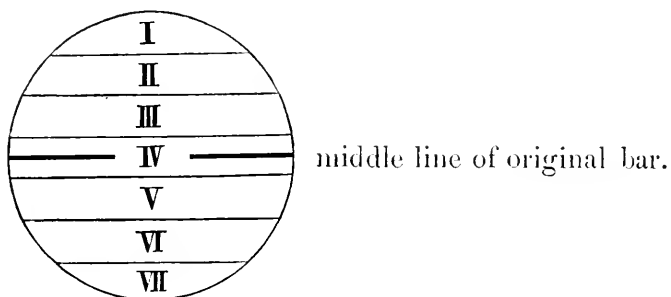
We selected four bars from four different melts named A, B, C, and D, the granulation assays of which were carefully made. These were rolled down to the required thickness as usual. Three blanks were cut out from each of the fillets, one from the middle and one from each end. These were marked respectively,  $A_2$ ,  $A_1$ ,  $A_3$ ;  $B_2$ ,  $B_1$ ,  $B_3$ , &c. &c., the direction of lamination of the bar being carefully marked on each blank. These blanks were then treated exactly the same as the blanks for regular coinage. Care was taken in annealing to place each of them among separate lots of ordinary blanks, so as not to allow the effect of any accidental irregularity to fall simultaneously on all of them. The loss of their weight in grains in annealing and pickling is shown in Table I.

**Table I.**  
Showing Loss in Annealing.

Mark of Blank.	Weight before Annealing.	Weight after Annealing and Pickling.	Loss in the Operation.
$A_1$ .	415.74	415.65	.09
$A_2$ .	415.98	415.89	.09
$A_3$ .	415.87	415.78	.09
$B_1$ .	416.51	416.39	.12
$B_2$ .	415.89	415.70	.19
$B_3$ .	415.83	415.73	.10
$C_1$ .	415.61	415.52	.09
$C_2$ .	416.06	415.97	.09
$C_3$ .	415.63	415.53	.10
$D_1$ .	415.92	415.84	.08
$D_2$ .	415.76	415.69	.07
$D_3$ .	416.21	416.13	.08

Each blank was then marked with six lines parallel to the direction of rolling, and cut into seven strips of equal breadth which were named as in Figure 1.

*Fig. 1.*



The narrow strips thus obtained were cut into smaller pieces and assayed. The results of the assays are incorporated in Table II. Assaying was conducted by the usual volumetric method. The proportion of silver was estimated to  $\frac{1}{10}$  of 1 per mille. When it is given to the second place of decimal, the number is the mean of several experiments.

Table II.  
Showing Fineness at Different Portions of Blanks.

Name of melt.	A.			B.			C.			D.			Average of Composite Fineness.
Granulation assay of the melt.	899.10			898.75			899.35			898.75			
Section of blank.	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	
I.	898.50	898.55	898.62	898.45	898.57	898.20	898.80	898.43	898.53	898.50	898.07	898.90	898.508
II.	899.15	899.72	899.07	899.48	899.68	899.08	899.91	899.05	899.62	899.15	899.00	899.66	899.383
III.	900.95	901.27	900.67	900.83	901.68	900.71	901.20	900.57	900.98	901.05	900.50	900.85	900.888
IV.	903.10	902.77	901.42	901.07	902.03	901.80	902.55	902.20	902.02	902.90	903.00	901.60	902.222
V.	901.97	900.85	902.67	899.85	900.03	899.94	901.15	902.88	900.57	901.18	901.76	900.15	901.109
VI.	899.55	899.15	900.62	898.70	898.70	898.70	899.51	900.78	899.60	899.34	899.78	899.27	899.480
VII.	898.70	898.10	899.25	888.12	897.67	898.15	898.83	899.10	899.06	898.52	898.57	898.56	898.573
Mean of all assays made on Blanks.	900.487	900.387	900.397	899.750	900.117	899.826	900.617	900.787	900.231	900.341	900.501	900.129	General Average
Average Fineness of Blanks.	900.427			899.899			900.578			900.352			900.307

In order to show the distribution of silver on the coin, we produce below the details of assay of the blanks  $C_1$ ,  $C_2$  and  $C_3$ , the figures which denote the fineness indicating as nearly as possible the relative positions of the respective portions.

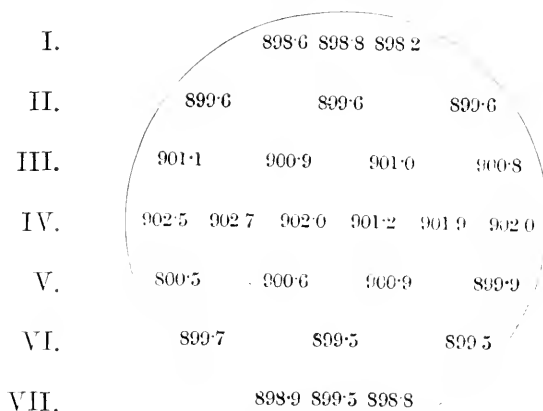
*Fig. 2.*Blank  $C_1$ .

I.	S98.7 S98.8 S98.9					
II.	900.8	900.0	899.6	899.5	899.8	
III.	901.6	901.2	900.6	900.9	901.1	901.8
IV.	902.2	901.9	902.2	903.2	902.7	902.6 903.1
V.	901.2	901.2	901.0	901.7	900.4	900.9 901.7
VI.	S99.6 S99.1 S99.4 S99.7 S99.6 S99.7					
VII.	S98.9 S99.0 S98.6					

*Fig. 3.*Blank  $C_2$ .

I.		898.8	898.4	898.1		
II.		900.4	898.7	899.0	898.3	
III.		900.6	900.3	900.8	900.5	
IV.		900.8	902.0	901.8	902.7	902.7
V.		903.1	902.9	902.5	903.0	
VI.		901.0	900.6	900.6	901.1	
VII.			899.0	899.4	898.9	

*Fig. 4.*  
Blank  $C_3$ .



	$C_1$ .	$C_2$ .	$C_3$ .
Average of all assays.	900.617.....	900.787.....	900.331
Highest assay.	903.2 .....	903.0 .....	902.7
Lowest assay.	898.6 .....	898.1 .....	898.2
Difference between highest and lowest assays.	4.6 .....	4.9 .....	4.5

The preceeding results furnish fresh illustrations of the well known fact, that, in an ingot made of the alloy containing 900 per mille of silver and 100 of copper, there is a segregation or concentration of silver towards the central line of the ingot. The middle portions in such an ingot contain the highest proportions of silver, while copper predominates along the edges. We observe in the blanks under examination that this difference may be as much as 4.9 per mille, as in blank  $C_2$ . It is also to be observed that even adjacent parts lying in the same line may show a considerable difference in composition, which is probably due to several causes. We may, however, regard each of the strips which we have prepared as of one fineness by taking the mean of all the assays made from it. Taking

the strip IV as the middle, the strips I, II and III, lie on one side of the central line at the same distances as VII, VI, and V, respectively on the other.

Comparing the numbers corresponding to each of these strips, we obtain the results shown in the following table.

**Table III.**

Showing the difference of fineness between two similar portions of blanks.

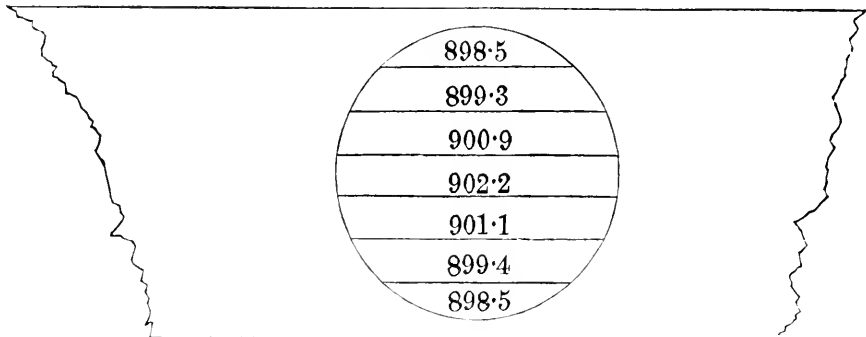
Mark of Blank.	Difference in fineness between strips.		
	I—VII.	II—VI.	III—V.
$A_1$ .	0.20	0.40	1.02
$A_2$ .	0.15	0.57	0.42
$A_3$ .	0.63	1.55	2.60
$B_1$ .	0.33	0.72	0.98
$B_2$ .	0.90	0.98	1.65
$B_3$ .	0.05	0.38	0.77
$C_1$ .	0.03	0.43	0.05
$C_2$ .	0.67	1.73	2.31
$C_3$ .	1.53	0.02	0.41
$D_1$ .	0.02	0.19	0.13
$D_2$ .	0.50	0.78	1.26
$D_3$ .	0.40	0.39	0.40

We may conclude then that the metal lying in the central line of the original bar shows the highest average fineness, while on both sides of this line, the fineness gradually decreases towards the edges,

and the strips which lie parallel to and equidistant from the middle line have nearly the same fineness. The correspondence is not strictly exact as may be seen in Table III. The small divergences may be due, apart from slight irregularities occurring in the metal itself, to the fact that the strips, into which the blanks were cut, were not, from instrumental causes, mathematically corresponding divisions of the original bar.

In order to eliminate, as far as possible, the effect of such irregularities, we have taken the mean of the several blanks as given in the last column of Table II. Thus we obtain, so to speak, an ideal composite blank or coin the fineness of the several parts of which is represented in Fig. 5.

*Fig. 5.*



The fineness of the entire blank = 900.3.

We also see that on an average the coins produced from a melt are about 1.3 per mil higher in fineness than the assay of granulations of that melt, as shown in the following statement :—

	A.	B.	C.	D.	Mean difference.
Assay of granulation of melt	899.10	898.75	899.35	898.75	
Average fineness of blanks	900.427	899.899	900.578	900.325	
Difference. ....	1.327	1.149	1.228	1.575	1.319

### III. Methods of Cutting Portions for Assay from the Coin.

If the figures given in the preceding section be taken as representing the general distribution of silver in the One Yen Coin, what would be the best mode of cutting portions for assay from it in order to ascertain the exact fineness of the piece?

It is almost superfluous to mention that the assay of the entire piece of such a large coin as the Silver Yen, being rather cumbersome, it is usually convenient to take about one gram of it for an assay.

It would be comparatively easy to cut out an exact representative sample from the coin, if the direction of rolling were apparent on its surface, for we should then know which was the central or richest part. Such is the case with blanks before they are treated with dilute acid. But in the coin, marks are obliterated, and portions must be cut from such positions that they represent the entire piece as nearly as possible, in whatever relation they may stand with regard to the direction of rolling of the bar, from which the particular coin has been prepared.

Four methods of cutting a coin for assay, besides our own, are known to us, and we will proceed to examine each of them.

Method *a*. A small portion is cut off from the rim of a coin, which, in some cases, is partly laminated by means of a pair of rollers previous to cutting. Since we know that the fineness at different parts differ so greatly, this method of single cutting must be at once rejected, as being unsuitable for large silver coins.

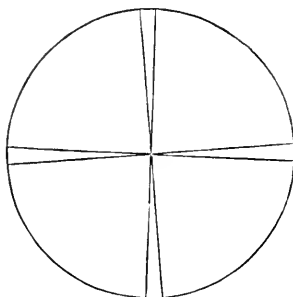
Method *b*. In the assay laboratory of the Bureau of the Mint at Washington the standard silver dollar is first rolled out into a very thin ribbon by means of a pair of small rollers; an innumerable number of small discs is then punched out of all parts of this ribbon,



a miniature cutting machine similar in construction to that used in minting operations being provided for the purpose. The discs are then well mixed and a number of them is weighed into a single assay. This method involves a considerable amount of labour in rolling and cutting, especially when a large number of coins is to be daily assayed. It may perhaps be difficult to guard the small and thin discs belonging to a particular coin against contamination with very minute scraps of silver detached from another coin operated in the same machine. Besides we are inclined to think that a number of such discs, unless indeed they be very minute, taken together for an assay does not always represent the average sample of the whole coin. Some experiments made by us in this connection show that the results of many assays made on a single coin are not sufficiently concordant.

Method *c*. A method formerly employed in the Imperial Mint consists in cutting four equal isosceles triangles from diagonal positions as shown in Fig. 6., the sharp angles of the triangles meeting at the centre of the coin, and the four portions when put together weighing almost exactly the weight required for an assay.

*Fig. 6.*



As may be understood from the nature of segregation already explained, this method does not provide the true representative sample

of the coin, and is far from affording concordant results when several assays are made of the same coin. If any pair of the diagonally cut triangles should happen to fall on the middle line of the original bar, represented by the central strip in Fig. 5, they would be of an excessively high fineness, while the other pair of triangles, although lower in fineness, would not be sufficiently low to counterbalance the excess of fineness of the first pair. The result would be the indication of too high a fineness for the coin. This assay being evidently too high, the assayer would now cut two other pairs of triangles from portions of the coin which lie between the first cuttings and assay them. The result would be as a rule to give too low a fineness; equally evident, the mean of the two assays being probably nearer the truth. In the case of the first assay being too low, the second assay would be similarly too high. Hence in the double assays, which were necessitated from this cause, made on 121 coins between January and September, 1887, the percentage of differences in fineness between two assays of the same coin were as follows :

Difference nil ... ..	1.7 %
Difference of between 0.1 and 0.5 per mille ...	4.9 ..
„ „ 0.6 and 1.0 ... ..	4.9 ..
„ „ 1.1 and 1.5 ... ..	28.1 ..
„ „ 1.6 and 2.0 ... ..	34.7 ..
„ „ 2.1 and 2.5 ... ..	17.4 ..
„ „ 2.6 and 2.7 ... ..	8.2 ..

Besides, there is always a difficulty in cutting the thick silver coin in the required form by means of a pair of shears, so that the weight of the cut portions is sometimes wide away from the mark.

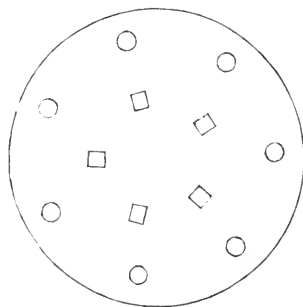
Although the assays of individual coins are thus considerably vitiated in correctness, the mean of a sufficient large number of coins individually assayed may agree closely with the assay of all these coins

melted together. But this agreement, it is needless to remark, does not sufficiently prove the correctness of the individual assays. The remark however applies equally well to any other method. We refer to this, because the said agreement has been put forward as an argument in favour of this method.

Method *d*. This method, due to M. Stas of Belgium and in use in the mints at Brussels and at Paris, consists in punching out small pieces from certain portions of a coin by the single action of a special machine. These pieces put together make up an assay. The number, positions and forms of the punchings differ in different denominations of coins and have been determined by experiment and calculation.

In the case of the 5 Franc Silver coin, similar in size to the Silver Yen, they are as represented in Figure 7.

*Fig. 7.*



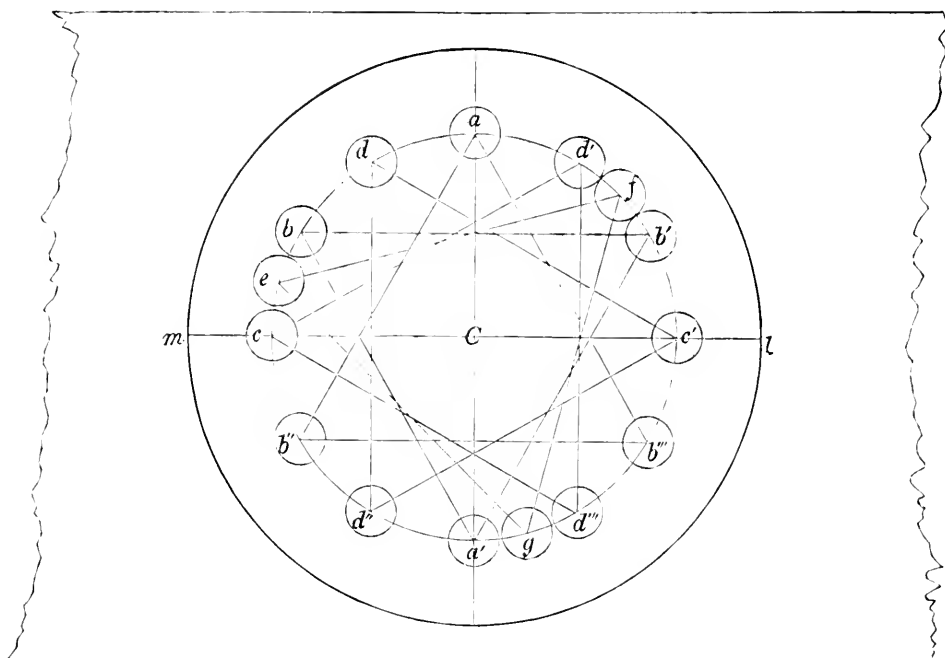
The punchings taken from inner parts are distinguished by a square form.

This method as applied to the Silver Yen coin appears to give remarkably exact results. We discovered however that the cutters being necessarily of a slender form frequently meet with serious accidents, so that after trying the machine for a considerable time, we were obliged to give it up and substitute for it another and simpler form described in the next paragraph.

**New Method.** A careful study of the distribution of silver in the coin has induced us to choose for our assay of the Silver Yen, three circular punchings of equal weight taken from the angles of an equilateral triangle, which may be supposed to be described on the coin, the distance of the centre of each punching from the circumference of the coin being made equal to one-seventh of the diameter. Portions of metal taken from any set of such positions when put together, give almost exactly the average fineness of the entire coin, of which therefore they are the true representative sample.

Thus in Figure 8, let  $c$  be centre of the coin,  $ml$  be its diameter and the middle line of the bar. Let  $cc'$ , diameter of the inner circle, be equal to  $\frac{2}{7} ml$ , and let equilateral triangles be described in this circle as shown.

*Fig. 8.*



Then from the nature of segregation in the coin, it will be readily seen that,  $c=c'$ ;  $a=a'$ ;  $b=b'=b''=b'''$ ; and  $d=d'=d''=d'''$ . Therefore the small punched out circles at  $a, b, c$  = the same at  $a', b', c'$ ; and the circles at  $d, d', d''$  = the same at  $d', d', d''$ . In the same way it may be shown that the circles at  $e, g, f$ , have their equivalent set.

Now by interpolation from a curve based on the numbers in Figure 5, we get the fineness of the parts marked  $a, b, c$  &c. on the ideal composite coin as follows :

$a = a'$ .....	=	899.0
$b = b' = b'' = b'''$ .....	=	900.8
$c = c'$ .....	=	902.3
$d = d' = d'' = d'''$ .....	=	899.3
$e$ .....	=	901.7
$f$ .....	=	899.9
$g$ .....	=	899.1

The three punchings may be any one of the sets above indicated or those lying between them; the resulting fineness of the sample will be nearly identical with each other and with the exact fineness of the composite coin, as shown in Table IV.

**Table IV.**

Showing the Fineness of three portions in the ideal composite Coin of fineness 900.3.

Position of Punching.	Fineness.	Average Fineness of the three Portions.
$c$ or $c'$	902.3	900.3
$d'''$ or $d''$	899.3	
$d'$ or $d$	899.3	
$e$	901.7	900.23
$g$	899.1	
$f$	899.9	
$b$ or $b''$	900.8	900.2
$a'$ or $a$	899.0	
$b'$ or $b'''$	900.8	

Numerous double assays of individual coins by this method have been made. The results do not indeed show absolute coincidence, but the agreement has been in most cases quite close.

Thus double assays made by this method on 105 coins gave the following percentage occurrences of differences :

Difference nil..... = 19·1 %

Difference of between 0·1 and 0·5 per mille = 59·0 „

„ „ „ 0·6 and 1·0 „ = 18·1 „

„ „ „ 1·1 and 1·5 „ = 2·8 „

„ „ 1·6 ..... = 1·0 „

The correctness of the results obtained by this method has been verified by us in many instances by the direct assay of the whole coin, after taking the portions for assay by punching, the coin being cut up into small parts and divided into as many assays as there are pieces of metal. In other instances the entire coin, after the removal of the punchings for assay, has been dissolved in nitric acid and made up with water to a certain known volume, an accurately calibrated bottle of about 2½ litres capacity being used for this purpose. An aliquot part of this liquid was taken up in a Stas pipette. The liquid was then transferred to a shaking bottle and assayed after having been evaporated on the water-bath to the same degree of concentration as in ordinary assays. The results have shown in all cases a close agreement between the assay on the punchings and the exact fineness of the coin ascertained in this way.

**Table. V.**

Showing the results of assays by the new method  
on coins whose compositions have been  
accurately determined.

No. of Experiment.	Assay on Coin.	Exact known fineness of coin.	No. of Experiment.	Assay on Coin.	Exact known fineness of coin.
1	899.8	899.75	14	899.7	899.82
2	900.8	900.67	15	899.9	900.61
3	900.3	900.62	16	900.7	900.78
4	899.8	900.37	17	899.8	900.33
5	900.1	900.47	18	899.7	900.34
6	900.1	900.25	19	900.3	900.12
7	899.6	900.15	20	900.5	900.50
8	900.0	900.30	21	900.4	900.59
9	900.3	900.20	22	900.6	900.59
10	899.6	899.80	23	900.4	900.81
11	900.6	900.58	24	900.5	900.39
12	899.6	899.75	25	900.2	900.48
13	900.0	900.11	26	900.0	900.39

The assays of granulated dips taken from the melted mass of a large number of coins, which had been individually assayed by this method, also shew a close approach to the average of the individual assays. In melting, special care was taken to cover the metal with powdered charcoal.

**Table VI.**

Showing Assays of Mass compared with  
Average of individual Assays.

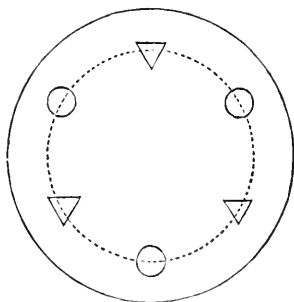
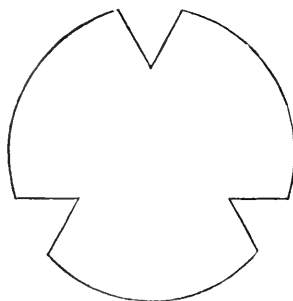
No. of Experiment.	Number of Coins melted together.	Assay of Granulated Dip.	Mean of in- dividual Assays of all the Coins.
1.	130	899.90	899.90
2.	50	900.10	900.04
3.	64	900.00	900.08

A small screw press worked by hand is used by us for cutting out the small circles from the coin (Fig. 9.), one circle being punched out at a time. A steel punch of the required diameter is attached to the screw. The coin is introduced by means of a brass sliding guide. The constant position which the guide is caused to take brings the coin to the exact relative position with regard to the punch. The latter descends by the action of the screw and cuts out a circular piece from the required position. The coin is then turned round through an arc of  $120^\circ$  in the guide by bringing the hole made by the first punching opposite a mark on the guide. A second action of the screw punches out another circle. The coin is turned round another  $120^\circ$  and the third circle is cut out. The process is simple and may be performed in less than half a minute. The somewhat large size of the cutter, or punch, and the very simplicity of the apparatus make any accidents extremely rare.

In this apparatus, the punch strikes out circular pieces of almost exactly the same weight. In default of the punch, we recommend the



following method of cutting which may be performed with a pair of shears. It consists in cutting three equilateral triangles as shown in Figure 9.

*Fig. 9.**Fig. 10.*

The centre of gravity of the triangles should be upon the circumference of the inner circle whose diameter is equal to  $\frac{5}{7}$  of that of the coin.

In order to facilitate the cutting of such triangles of equal weight, it is advisable to use a pattern of tin plate cut as shown in Figure 10.



## APPENDIX.

### Note on the Stas Pipette.

The Stas pipette used by the writers in the assaying of silver delivers a nearly constant volume of liquid as shown in the following statement :—

Weight of water at 70° F. delivered by the Stas Pipette.

Time occupied in delivery = 13 seconds.

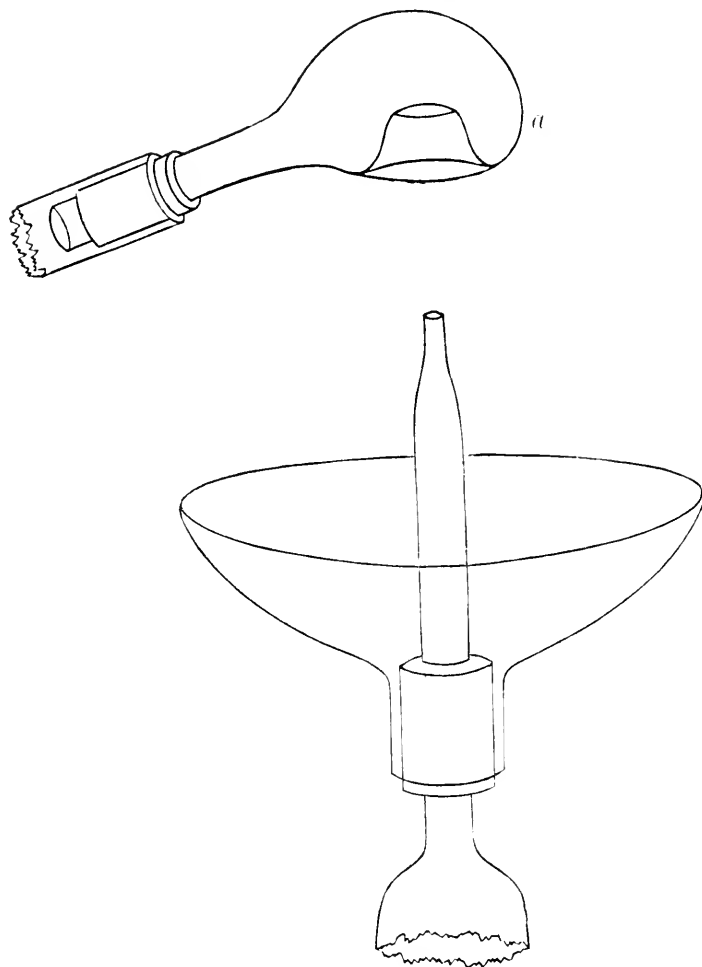
Experiment	I.	.....	1000·140	grains
„	II.	.....	1000·146	„
„	III.	.....	1000·129	„
Mean			1000·1383	„

In the arrangement of common forms of the pipette, a shallow bell-shaped glass is suspended over the top of it. Any excess of the liquid, which is introduced from below and is projected upwards, strikes against the glass and is caused to drop down into the glass dish adapted to the neck of the apparatus. There is in this arrangement a constant danger of the dish overflowing, and even of the liquid being splashed out on the table.

The arrangement employed by us consists of an overflow tube instead of the bell-shaped glass. It is said to have been first devised by the late Mr. W. E. DuBois, assayer in Philadelphia Mint, and has been adopted in that mint and also in the Royal Mint in London. In the form used in those institutions it is constructed of gutta-percha. But as made by us it is of glass, and with a little manipulation in the blow-pipe, may be easily constructed in the laboratory from a piece of bulb-tubing.

The apparatus consists of a glass bulb *a*, Fig. 11, blown on one end of a tube. The under side of the bulb is made into a cavity the top of which is cut open into a hole, thus forming a circular groove inside the bulb. The head of the Stas pipette comes just below the cavity.

*Fig. 11.*



The liquid is filled into the pipette from below as usual ; any excess of liquid is projected by its own force into the bulb above.

and thence round the inner groove, quietly flowing away by the inclined tube to any suitable receiver placed at the end of the tube, without fear of spilling or splashing.

The Imperial Mint, Osaka.

April. 1890.





# On Cordierite as Contact Mineral

by

Yasushi Kikuchi.

With Plate XXVIII.

The occurrence of Cordierite in some metamorphosed rocks along the margin of the granitic intrusion has often been recognized in many places in Europe. In this condition, however, the mineral seems to be only of secondary prominence, being usually found as formless grains associated with other minerals of contact origin, such as Andalusite, &c. The case which we have to describe is of especial interest, since so far as we know, it is an instance in which this mineral has been solely developed as a result of contact metamorphism in a very peculiar modification, differing from the ordinary form of Cordierite by want of pleochroism, and the structural habit of its crystal which is hitherto unknown.

The volcanic product of Asama-yama has yielded an interesting Cordierite-rock, which was microscopically studied by Dr. E. HUSSAK.\* This Cordierite, the characters of which I was also able to examine myself by the specimens kindly furnished to me by Dr. T. HARADA, differs from that here to be described, as might have been expected from the different mode of its origin.

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\* Ueber den Cordierit in vulkanischen Auswürflingen—Sitzungsb. d. k. k. Akad. d. Wiss. in Wien. Mathem.-Naturwiss. Classe, 1883, Bd. LXXXVII, p. 332.

The following article is an account of the results which have been obtained principally by the study of the specimens collected from the bordering region of the Provinces Kōdsuke and Shimotsuke, along the Watarase-gawa, where the mineral is developed in its most typical and fresh state. Previous to the discovery of this occurrence the attention of geologist was drawn to an interesting pseudomorphic mineral found imbedded within a dark slate developed at the granitic border, near the town of Kameoka in the Province of Tamba. It is always found in a prism of hexagonal form, apparently cleaving parallel to the base, and consisting essentially of a greenish coloured mica. It is generally known as *Sakura-ishi* (cherry-stone), as its hexagonal cross section presents a radial arrangement like that of a flower. With regard to the nature of this pseudomorph, nothing definite was known, for the original mineral which had given rise to it, was not discoverable at or near the locality mentioned. It was generally supposed to have been derived by alteration from some such mineral as Andalusite. Close examination showed, however, that there is a striking analogy of structure existing between this pseudomorph and the fresh specimen developed at the contact zone of the Watarase-gawa region above referred to. Here also crystals occur in a dark slate. They were proved to have the essential characteristics of Cordierite, and on being altered gave rise to a pseudomorph analogous to the "cherry-stone" of Tamba.

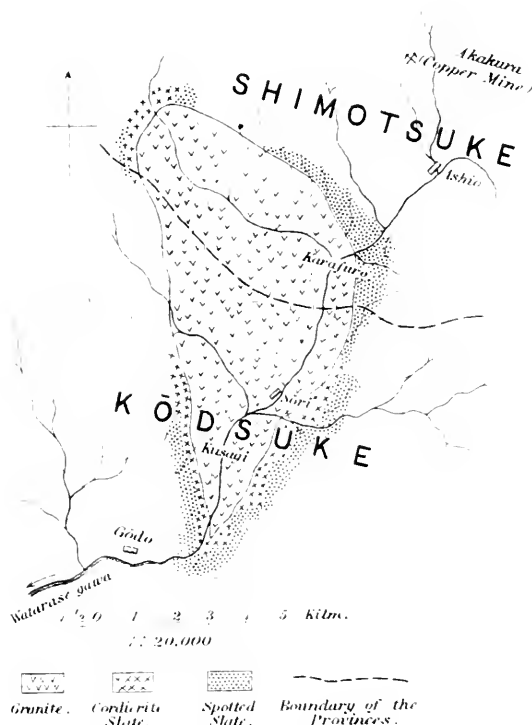
DR. GEERTS\* gives the description of *Sakura-ishi* under the variety of 'Chlorite hexagonale et lamellaire.' It is mentioned as having a pale rose (?) colour, and consisting of elongated hexagonal prisms made up of tender and flexible laminae. His specimen is said to have come from Prov. Mikawa.

The occurrence of Cordierite in the Watarase-gawa region was

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\* Les produits de la Nature, Japonaise et Chinoise, p. 433.

first noticed by the writer in the summer of 1887. By occasional trips undertaken since then, the geological condition of the district has been made out, the summary of which may here be sketched as follows :—



The Watarase-gawa, a tributary of Tone-gawa, takes its origin behind Lake Chiuzenji in Nikkō, near the Copper mine of Ashio in Shimotsuke, and flows south-westward for about 35 kilometres, along the strike-line of the Palæozoic strata here developed, to the town of Ōmama in Kōdsuke.

Here it leaves the mountainous region and makes a sudden turn to S. E., entering the plain of Kwantō. An elliptical mass of Granite makes its appearance along this river, beginning at the village of Karafuro near Ashio, and ending near the village of Gōdo in Kōdsuke, extending nearly 11 kilom. from N. to S, and 5 kilom. from E. to W. The southern extremity of this granitic mass gradually tapers and merges itself under the thick Palæozoic layer, granitic exposures appearing here only in the river-bed; while the bordering ridges are composed of sedimentary rocks, which are



often invaded by apophyses. As we proceed northward, the granite gradually gains over the higher level, attaining its maximum breadth just where the Watarase-gawa passes the boundary of the two Provinces already named. Further north of this point, it again loses itself under the sedimentary rock masses. The whole of these phenomena suggests that a huge granitic mass has been forced up from below, probably along a line of fissure running N. and S., partially represented by the valley of the Watarase-gawa, into the overlying stratified rocks. The accompanying sketch map may serve to illustrate the brief description just given. The altered zones are marked at those places only where they have been actually observed.

The Granite developed in this region is composed of Quartz, Orthoclase, and Biotite, with some accessory minerals; Garnet, microscopic Zircons, &c. The structure is usually uniformly granular; sometimes porphyritic by the development of Orthoclase into large tabular crystals having zonal inclusion of mica flakes.

The thick strata of the Palaeozoic date (probably the 'Kobotoke' system of the Geological Survey) developed around this granitic mass consist of hard sandstone,—the 'Greywacke'—Hornstone, Slate, and some Limestone, all non-fossiliferous. Their direction of strike is N. E., dip generally toward S. E. Wherever these rocks come into contact with Granite they undergo peculiar alteration. The hornstone is converted into a harder Quartzite, the fresh fracture of which shows a fine granular saccharoidal appearance; the sandstone becomes more compact in texture and much mica is developed in it. But that which concerns us here is the effect of metamorphism on the Slate. The first sign of alteration of this rock is manifested by the development in it of fine black specks, which examined under the microscope are seen to consist of aggregates of black mica. This

kind of spotted slate is followed toward the Granite by a narrow zone of altered slate containing the characteristic crystals of Cordierite. The Cordierite-bearing slate is found close to the Granite and usually no particular indication of metamorphism can be detected other than by the presence of these crystals, or else by the compact texture, like that of 'Hornfels,' which it assumes. This inner zone is comparatively narrow in breadth, and exposures of some 10 *metres* may be seen cropping out at the immediate vicinity of the Granite, while the outer zone is usually broader, being double or treble of the inner.

Microscopically examined the ground mass of the Cordierite slate differs, in no essential respect, from the spotted slate already mentioned, consisting of minute quartz grains, and a black mica, with irregular dots of opaque carbonaceous matter.

I am indebted to Mr. T. Nasa for the following chemical analyses of the slate, which were made in the laboratory of the Geological Survey.

	I.	II.	III.
$Si\ O_2$ .....	66.10%	67.50%	74.50%
$Al_2\ O_3$ .....	16.39	14.65	14.20
$Fe\ O$ .....	4.65	6.46	4.45
$Fe_2\ O_3$ .....	.30	trace	.30
$Ca\ O$ .....	1.60	1.10	.50
$Mg\ O$ .....	2.41	1.90	1.62
$K_2\ O$ .....	3.36	3.76	2.08
$Na_2\ O$ .....	1.86	2.79	.94
$H_2\ O$ .....	3.60	2.00	1.33
	<hr/> 100.27	<hr/> 100.16	<hr/> 99.92

I. is the slate with the Cordierite crystals, which showed a slight sign of alteration, assuming a greenish tinge. The large

amount of water is no doubt due to this alteration. Loc. Sōri in Kōdsuke.

II., is the same as I., but with all the visible crystals of Cordierite removed.

III. is the ordinary unaltered slate. Loc. near Gōdo in Kōdsuke.

From these few analyses nothing quite certain can be asserted. It may be pointed out, however, that the relative amount of silica is less in the altered slate with Cordierite than in the unaltered one without any Cordierite, allowing that there was no very great difference in the original character of the two slates taken for the analysis. On comparing II. and III., we see that the altered slate approaches, on the whole, to the normal slate by the partial removal of the Cordierite crystals. It is probable that by the process of contact alteration, the slate was made basic by the addition of the Cordierite-silicate.

The Cordierite-bearing slate presents a very characteristic appearance in virtue of the elongated fusiform sections of the crystals irregularly scattered in the general ground-mass. Further, on closer observation, rounded six-sided sections may often be detected. In weathered pebbles which have long been exposed to atmospheric action in river-beds, &c., the crystals are more readily recognizable than in the freshly fractured surface, on account of the fact that natural corrosion has been more active on them than on the surrounding mass, so that they are often found depressed at the exposed surface. They are also stained reddish-yellow by the iron hydroxide, which has probably partly resulted from the oxidation of the Iron-pyrites which they contain (Fig. 7). In those specimens, however, which have undergone more or less metasomatic alteration, a greenish tinge is always observable, resembling the pseudomorph from Tamba. Sometimes stellate aggregates, which are probably due to twin-groups, are observed (Fig. 8). As the form of such aggregates

has a cherry-blossom like structure, the cordierite-slate was known by the name of *Sakura-ishi*, as in the case of the Tamba specimen. The size of the crystal is variable ; usually about 2 *cm.* in length and 5 *cm.* in breadth ; but in some cases it attains the much larger dimensions of some 5 *cm.* in length and 1.5 *cm.* in breadth. In specimens in which the alteration has not much advanced, the fresh portion is colourless and transparent, and the fracture presents a highly vitreous lustre like that of quartz.

The *transverse section* of the Cordierite crystal always presents an hexagonal figure divided up into sectors (Fig. 1), the boundaries of which are formed by the filling up of the black carbonaceous matter. There is usually in the interior a central nucleus or core, also hexagonal and parallel to the outer boundaries, but apparently devoid of any radial divisions or sectors as in the outer.

Under polarized light the different sectors are found to differ in optical orientation ; the opposite pairs, however, behaving alike. Thus we see that the crystal must be made up of the union of three individuals according to a twin law, forming a *Trilling*, which, as is well known, often assumes a pseudo-hexagonal symmetry, when the twinning plane is a prismatic face having an angle near to  $120^{\circ}$ . This twin, which was first observed in the specimen from Bretagne by DES CLOIZEAUX,\* is very characteristic of Cordierite, and has also been described from the Asama and the Laach crystals.† But there are in the case which we are now describing some points of peculiarity, which have not been recognized in the others. These are, firstly, the separation of the cross section into the outer and the inner portions,

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\* Manuel de Mineralogie, I. p. 355.

† HUSSAK, (l. c.) and v. LASAULX—Ueber Cordierit-zwillinge in einem Auswürflinge des Laacher Sees—Zeitschrift. f. Krystall. 1884. VIII, p. 76.

which exhibit some difference in structure; and, secondly, the inclusion of foreign matter in the boundary between the outer and the inner portions, and between the twinning sutures in the outer portion.

The *inner portion* or the core is different in character from the outer, as may be easily revealed under the microscope by the use of polarized light. The twin-structure is soon evident under crossed Nicols, but the three systems of the twinned individuals often interpenetrate in a very complex and irregular manner. Figure 3, is a magnified representation of the structure of the inner portion, in which the different patches having an analogous optical orientation are represented by the same shading. It will be observed that these different patches are reducible to three systems which are continuous with those of the outer portion. The directions of extinction, therefore, in the outer and the inner portions, are always parallel and at right angles to the outer sides, and differ by nearly  $60^\circ$  from each other.

Under a convergent polarized ray the different sectors of the more uniformly built *outer portion* show the Axial-image (Interference-figure), the position of which in each sector is represented in Figure 1. The Optical-plane is situated at right angles to the outer side of the crystal, and therefore it is in the Macropinacoidal face (100), as in this twin the outer side corresponds to the Brachypinacoid (010). The Axial image examined with mica plate reacts negative, with a weak dispersion,  $\rho < v$ . The distance between the two rings of the image is not very wide.

Traces of cleavage-plane are often distinctly seen in the transverse section, as fine fissures always running parallel to the outer sides, i.e., parallel to the Brachypinacoid (010). In Figure 1, the fine lines parallel to the sides are the traces of cleavage, while the thicker

lines at right angles to it are peculiar lines of structure, which are represented by fine clefts or by the parallel arrangement of foreign matters, chiefly carbonaceous particles. On close examination, we can often observe the indentation at the corners of the transverse section, formed by the intersection of the macropinacoidal faces of the neighboring individuals. Figure 12 shows an example in which the twin-individuals are widely separated from each other by the development of the macropinacoidal faces.

The *longitudinal section* always presents a rectangular outline. Very often both extremities are a little narrower than the middle portion, presenting a fusiform appearance. It is always intersected by two diagonal lines, which are formed by the accumulation of coaly particles, crossing at an angle of nearly  $20^{\circ}$ . The section is thus divided into an inner and the outer; the former being included by the acute, and the latter by the obtuse angle of the diagonal lines. Such a structure is analogous to that observed by HUSSAK\* in the Asama Cordierite; the diagonal lines of boundary being, in this case, made up of the chain of enclosures, which consist of irregular Augite and Magnetite grains and glass particles.

The structure of the inner and the outer portions are somewhat different. The inner portion is always fibrous in structure; the direction of fibres being arranged parallel to the longer side (Fig. 4, 5.) This must correspond to the central core of the transverse section which we have already described, and the fibrous appearance is no doubt due to the intermingling of the three systems of individuals in the twinning position. Examined under polarized light, the different fibres are different in colour, so that a beautiful display of the variegated bands is observed; this being due to the fact

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\* l. c. p. 348

that a longitudinal section meets the three twin individuals in dissimilar positions with regard to the optical plane. The different fibres have their maximum of darkness under crossed Nicols, when they are parallel and at right angles to the direction of the longer side.

The outer portion is generally homogeneous, and in those parts where the section falls at right angles to the optical plane, i. e., parallel to the face (010), an axial image may be observed under a convergent polarized ray. The image reacts positive by the mica plate, and the distance between the two rings is wider apart than in the case of the cross section.

The arrangement of *Enclosures* is different in the inner and the outer portions. These enclosures are mostly chains of black carbonaceous particles. Under the microscope, however, we find very fine platy enclosures. Sometimes these platy enclosures are visible to the naked eye, and consist of a black lustrous mineral like Graphite, giving a decided reaction for manganese. In some cases Iron-pyrites is found also in the form of elongated plates. In the outer portion, these enclosures are set parallel to the macropinacoidal face of each twin individual, causing a radial arrangement in the transverse section, as shown by the thicker lines in Figure 1.

In the inner portion they are always arranged longitudinally, parallel to the direction of the longer side. Neither the pleochroic halos nor the needle-like inclusions, which have been described as very characteristic of some Cordierite, have ever been observed accompanying these enclosures.

The boundaries of twinning, and of the inner and the outer portions are formed as we have stated, of black coaly particles. Associated with the carbonaceous matter are found numerous irregular grains transmitting a very pale pinkish colour, reminding us of Andalusite-grains. Besides these, there are often found very small

crystals having a very sharp outline. They are in slender prisms with pyramidal ends. They are most probably Zircon-crystals.

The peculiar forms presented by the transverse and the longitudinal sections tell how the crystal is built up. Figure 2 is an idealized representation of the structure of the crystal as constructed from the forms of these sections. The horizontally shaded portion in the figure is the boundary between the inner and the outer portions. These planes of division, which correspond to the Brachydome in each twin individual, together form a double pyramid, the apices meeting at the middle. They are always formed by the filling in of black grains of carbonaceous matter. From this figure it is evident that the relative magnitude of the inner and the outer portions must differ in the transverse sections, according to their respective distances from the centre. In microscopic sections which were made at random from the slate, various forms of this gradation have been observed; it is not uncommon to meet the section passing very near the centre or just at the centre, having a very little or no central portion (Fig. 12.)

This peculiarity in the structure of the crystal is probably to be explained by the manner in which the crystal has grown up during the process of its formation. It must be assumed that this growth took place in a medium not wholly suitable to the free development of the crystal. Thus we often find a number of rudimentary or skeletal forms of crystal, *e.g.*, such a one as represented in Figure 6. It consists of two sets of fine bundles disposed at right angles to each other. By comparing the various forms which are met with (*e.g.*, Fig. 4 with Fig. 5) it is easy to see that the finer set of bundles arranged longitudinally correspond to the inner portion, while the other set of the wedge-shaped bundles correspond to the outer portion of the crystal which we have been considering. It must be inferred from this, that the growth of the crystal took place in two principal directions at



right angles to each other, as indicated by the two sets of bundles. The planes of boundary of these two sets would be formed, in the better formed crystals, by particles of the carbonaceous matter existing in the mass of the slate. In the skeletal crystal such as noted above, these two sets are represented by scattered bundles separated by the larger interstitial spaces of the foreign material. It will be observed that the growth of the outer portion also took place laterally, in three directions in the position of the twin, so that the space between each individual was also filled up with coaly particles. But in the inner portion this was somewhat different; here the direction of growth was at right angles to the directive influence which would bring about the twin structure, and the peculiar manner in which this inner portion is built up, in contrast to the outer, must, we think, be in some way connected with this antagonistic state of the two directive forces. The arrangement of the enclosures already described (p. 322) also tells us the two directions of growth.

*Pleochroism.*—To the naked eye the fresh specimens appear colourless, there being practically no pleochroism. But on separating the fragments of the mineral from the matrix and on washing the adhering impurities of iron hydroxydes, it was found they distinctly exhibit a slight blueish tinge, which is generally so characteristic of this mineral. The property of pleochroism, however, seems to be absent in some Cordierite minerals, e. g., that described by P. Groth\* from Brazil.

*Corrosion-figures.*—The basal section was selected for experimenting on the production of corrosion-figures. On etching the smoothly polished face with hydrofluoric acid, it was found that the different sectors were covered with innumerable figures. The form of these figures was nearly spindle-shaped; and their longer axes arranged

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\* Ueber farblosen Cordierit aus Brasilien—Zeitschft. f. Krystall., 1883, Bd. VII, p. 594.

parallel to the Brachypinacoid (010), like those obtained on the Cordierite of Laach by HUSSAK.\*

*Chemical Composition.*—Some difficulty was experienced in collecting a sufficient quantity to serve as a pure sample for chemical analysis. Fragments of transparent portions were cautiously picked out by hand from the larger crystals, having the characteristic structure already described, as it was often difficult to distinguish these from Quartz-grains found in the slate. The black carbonaceous particles were avoided as much as possible. Fragments thus collected were washed with dilute hydrochloric acid, to remove the coating of iron hydroxide. Examined under the microscope, the sample was on the whole pure, but very small dusty aggregates of carbonaceous matter were generally attached to the fragments. It was also almost impossible to get the sample absolutely free from the beginning of the alteration which, even in fresh-looking transparent specimens, had set in from the very fine fissures. The analysis of the sample thus selected, was kindly conducted by Mr. T. SHIMDSU, with the following result:—

$SiO_2$ .....	48.43 %
$Al_2O_3$ .....	32.36
$FeO$ .....	8.55
$MnO$ .....	1.32
$CaO$ .....	.46
$MgO$ .....	7.81
$H_2O$ .....	1.55
	<hr/>
	100.48

Water must be ascribed to the beginning of the alteration. Manganous oxide is partly due to the fine platy enclosure already alluded to.

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\* l. c. p. 355. Tafel. II. fig. 28.

The composition of the mineral may probably be represented thus :—

		Oxygen-ratio.	
$SiO_2$	.....48.95%	.....26.10	.....5.2
$Al_2O_3$	.....32.71	.....15.24	.....3
$FeO$ ( $MnO$ )	..... 9.98	..... 2.21	} 5.55 ...1.1
$MgO$ ( $CaO$ )	..... 8.36	..... 3.34	
	<hr/>		
	100.00		

Thus we have

$$t\frac{6}{5}MgO \cdot \frac{4}{5}FeO \cdot 2Al_2O_3 \cdot 5SiO_2 = 6MgO \cdot 4FeO \cdot 10Al_2O_3 \cdot 25SiO_2,$$

which requires the following percentage composition :—

$SiO_2$	.....49.05 %
$Al_2O_3$	.....33.68
$FeO$	..... 9.42
$MgO$	..... 7.85
	<hr/>
	100.00

Hardness=7. Specific gravity=2.642, a mean of several observations as determined by the Thoulet's solution. A thin splinter fuses at the edge to a transparent globule, and gives a blue colour on being moistened with cobalt-solution and then ignited.

*Alteration*—It is a significant fact that Cordierite is a mineral which is easily subject to alteration at the surface of the earth ; so that we know more of the altered products in various modifications from different localities than of the unaltered mineral. The heterogeneous outward appearances presented by these products have created many ill-defined names, such as Praseolite, Aspasiolite, Chlorophyllite, Fahlunite, Gigantolite, Pinite &c. The final product of alteration is that usually known as Pinite, a pseudomorph consisting of

mica. The peculiar pseudomorph from Tamba already mentioned belongs no doubt to this category. In the specimens from the Watarase-gawa region, we can trace under the microscope the progress of the gradual transmutation from the transparent fresh mineral to its final stage.

The alteration first sets in from the irregular cracks traversing the crystal, somewhat like the formation of Serpentine from Olivine. In this first stage all that we can observe is, that there is formed along these cracks a greenish or white impellucid material in the form of a double layer (Fig. 10). This layer is found on close examination to consist of crystalline aggregates of a very fine fibrous mineral, exhibiting under crossed Nicols, an irregular aggregate-polarization. In most cases, however, we observe that the alteration proceeds along a series of very fine linear fissures, which are differently arranged in the different portions of the crystal, analogous to the arrangement of the enclosures already described. Figure 10 shows these fissures in a section parallel to the vertical axis, the irregular cracks, from which the alteration started, running in a transverse direction, while the linear fissures run at right angles to it.

The alteration gradually makes its progress, until there is left no trace of the original substance, and the final product is an impellucid crystalline substance which usually bears a greenish tinge. It is usually mixed up with some greenish coloured mica, which is sometimes only very sparingly developed, or often fills up almost the whole space. But it is in the specimens from Tamba that this mica is most typically developed as the sole product of alteration. In its outer aspect the altered product of the Watarase-gawa region generally looks like *Aspasiolite* from Kragaroë, Finland, while that of Tamba resembles *Chlorophyllite* from Haddam, Connecticut, U. S. A.

The pseudomorph from Tamba is of a greenish colour, imbedd-

ed in a slightly reddish coloured slate looking like 'Hornfels', and has a marked tendency to separate along the basal face. The hardness is somewhat low ( $H=2.5$ ). Before the blow-pipe, it fuses slightly at the edge. The crystal is built up exactly in the same manner as the unaltered crystals from the Watarase-gawa region, and therefore the forms of the transverse and longitudinal sections are exactly alike to those already described. The separation along the basal face is caused by the regular arrangement of mica-flakes parallel to the Base (001) of the crystal. This arrangement may be well observed in the longitudinal section. Figure 11 is a magnified view of this section, in which the fine lines are the cleavage traces of the mica-flakes. The black dots arranged in the form of rows or wedges, are the inclusions of carbonaceous matter.

Examined under crossed Nicols, the layers of mica extinguish the light simultaneously, and therefore form optically a continuous individual, but they are usually intermixed with irregularly arranged aggregates of the same mineral. The green mica is faintly but distinctly dichroic: when the ray of light vibrates parallel to the direction of the basal cleavage traces, it is of a light greenish colour, but is of a light yellowish tinge when the ray vibrates at right angles to this direction.

A. WICHMANN\* distinguishes two phases in the alteration of Cordierite. For example in case of *Chlorophyllite*, the first stage is characterized by the formation along the fissures of a certain crystalline fibrous substance, while in the second stage the alteration occurs essentially in the mica flakes. The two modes of alteration which we have distinguished above evidently correspond to these two stages. WICHMANN observes that the transition of the crystalline substance

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\* Die Pseudomorphosen des Cordierits—Zeitschft. d. deut. geol. Gesellft. 1874, Bd. XXVI p. 679.

into mica is rather abrupt, there being no evident sign of gradual passage. We are rather inclined to think that the formation of mica may directly follow as a result of alteration. For, in some cases, we find, that the fissures of the crystal are lined abruptly with the mica flakes, as if a thin clear cleavage-piece of this mineral were inserted between the fresh fissures. In such cases, which we could observe very distinctly in a specimen from the Watarase-gawa, the mica begins either to be formed very regularly disposed at right angles to the vertical axis, or from the sides of the crystal, sometimes parallel, sometimes very irregularly disposed, to the outer wall.

It would be of interest to know the chemical alteration which the altered Cordierite has undergone. A sample of the Tamba pseudomorph free from admixture, was analyzed, with care, by Mr. TAMURA of the laboratory of the Geological Survey. The result was as follows :—

<i>SiO</i> <sub>2</sub> .....	40·92 %
<i>Al</i> <sub>2</sub> <i>O</i> <sub>3</sub> .....	31·06
<i>FeO</i> .....	7·99
<i>CaO</i> .....	trace.
<i>MgO</i> .....	6·71
<i>K</i> <sub>2</sub> <i>O</i> .....	8·60
<i>Na</i> <sub>2</sub> <i>O</i> .....	·72
Loss on ignition .....	3·22
	<hr/>
	99·22    G = 2·77.

By comparing this result with that already given, we see there is a considerable addition of alkalis (potash) and of water, while the amount of silica is less. This pseudomorph, therefore, belongs to that class of the alteration-products of Cordierite, which has taken up not only water but also potash, and is essentially analogous to that

usually known as *Pinite*. The addition of potash was explained by G. Bischof\* as due to the action of circulating water containing in solution, the alkaline silicates which had been derived from the decomposition of granitic rocks. With this addition of potash there is usually a diminution of magnesia. But in the present case this loss is slight compared with the addition of potash. The amount of water is also a little less than is obtained for other *Pinites*.

From the foregoing descriptions it will be seen that Cordierite, as a product of contact metamorphism, presents many peculiarities which have been hitherto unobserved. These anomalous characteristics may be accounted for by the fact that the same mineral may assume different aspects according to peculiar conditions in which it was formed. This is well exemplified in case of *Andalusite* and *Chiastolite*. The latter is always found in the slate near the granitic contact, and is distinguished from the former by the well-known cross-inclusion of foreign matter, which seems to have been taken up during its growth, and by the absence or weakness of pleochroism. As this diagnostic difference has an important bearing upon the genesis of the crystal, it would be appropriate to emphasize the name of *Chiastolite*, so as to give it a signification distinct from that implied by *Andalusite*, notwithstanding the fact that both are physically and chemically identical. It would, in fact, be best interpreted as a *specific* title, according to G. TSCHERMAK'S\*\* definition.

The comparison which we have drawn is likely to be true also of Cordierite, since in the Japanese occurrence we have discovered its second modification or *species*, appearing in form and conditions analogous to those observed in *Chiastolite*. If, therefore,

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\* Lehrbuch der chemischen u. physikalischen Geologie, 2te. Aufl., Bd. II, p. 579.

\*\* Lehrbuch der Mineralogie, 2te. Aufl., p. 313.

the system of nomenclature above adopted is to be consistently carried out, it would be necessary to have a new appellation for it, to distinguish it from the ordinary form of Cordierite. For this purpose, we propose the name of CERASITE,\* from *κερασος*, *cherry*, in allusion to the fanciful designation of 'Sakura-ishi', by which it is generally known in Japan. *Cerasite* is, then, that form of Cordierite which has been produced by the so-called contact metamorphism of Granite in slate, and is characterized by the constant and regular form of the enclosure of the foreign materials, and the absence or weakness of pleochroism.

*Other occurrences*—Besides the localities already mentioned, there have been discovered other occurrences of *Cerasite*, some of which may be briefly noticed here. Pebbles of the contact-slate looking like that from the Watarase-gawa region were found in Hokkaidō by Mr. K. JIMBO, to whom we are indebted for the following list of localities as well as information regarding them.

1. Raruishi, Hutorogori, Prov. Shiribeshi.
2. Saruru, Horoizumigori, Prov. Hidaka.
3. Hurebets near Poronai, Esashigori, Prov. Kitami.
4. Toshihets gold-field, Prov. Shiribeshi.
5. Kenupchi, a branch of Teshio-gawa, Prov. Teshio.

In all these cases the slate is always found near the granitic mass, but the exposures *in situ* have not yet been observed. The specimens obtained from these localities are usually much altered into a greenish mica. Under the microscope, they present nothing very

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\* This name of *Cerasite* is sometimes defined as "native muriate of lead," on the authority of Dana. The reference to the 'System' (p. 703) shows, however, that it is another name for *Phosgenite* (*Hornblende* or *Cornecous lead*), otherwise known as *Kerasine* or *Cerasine*, which is derived from the Greek *κερας*, *horn*. Hence it is evident that *Cerasite* has had no objective significance.



characteristic; the greenish micaceous product fills up the whole space of the crystal as irregular aggregates. A tendency to arrange itself parallel to the base, as in the case of the Tamba specimens, is not observed. The specimen from the last locality given above, is the most interesting; the crystals are in a quite fresh state, but their development is rather rudimentary, consisting of finer patches and threads, yet exhibiting on the whole the characteristics already described.

We have to mention one other occurrence in the Main Island, viz. from Iriya-mura, Motoyoshi-gori, Prov. Rikuzen. It was also first observed by Mr. K. JIMBO. Here the slate is converted, near a small granitic boss, into a spotted slate looking exactly that developed in the outer zone in the Watarase-gawa region. Under the microscope the characteristic transverse section divided into six sectors may occasionally be observed. The crystals are very small and can only be detected under the microscope.

N. B.—We read in a recent number of the *Neues Jahrbuch für Mineralogie &c.*, (1889, Bd. I. p. 92, *Referat*. Original—“*Ein Beitrag zur Kenntniss der Knotenschiefer*” in *Verhandlungen des naturhistorischen Vereins der Rheinlande u. Westfalens*, 44, 1887) that Dr. E. HUSSAK has investigated the microscopic characteristics of some of the contact rocks chiefly of Germany. It is of interest to know that he has found in the spotted slate (Knotenschiefer) of Tirpersdorf in Saxony, an hexagonal section exhibiting the sectors, which he considers to be Cordierite. This is also found converted into a pseudomorph resembling Pinite.

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## Explanation of Plate XXVIII.

*Fig. 1.*—Transverse section of the Cordierite-twin, somewhat idealized, showing the optic orientation. The directions of cleavage are represented by fine lines parallel to the outer sides (010); and of interposition by thick lines at right angles to the sides, i. e., parallel to (100.)

*Fig. 2.*—Ideal form of the twin-crystal, consisting of the inner and the outer portions, the boundaries of which are marked by the shaded double-pyramid.

*Fig. 3.*—Transverse section to show the peculiar structure of the inner portion.

*Fig. 4.*—Longitudinal section with characteristic diagonal boundaries of the inner and the outer portions, and their directions of growth. Natural size.

*Fig. 5.*—The same, more perfectly developed.  $\times 2$ .

*Fig. 6.*—The same, but in a rudimentary or skeletal form, consisting of the fine longitudinal bundles corresponding to the inner, and the wedge-shaped cross bundles corresponding to the outer portions in Figs. 4 and 5.  $\times 3$ .

*Fig. 7.*—Thin slide of the slate from Watarase-gawa with two typical sections of Cordierite, the transverse (upper) and the longitudinal (lower) sections, with characteristic interpositions, coloured yellow by the infiltration of the iron hydroxide (Limonite). Natural size.

*Fig. 8.*—Transverse section of three united individuals, probably a twin-group, with a small transverse section to the left lower side. Natural size.

*Fig. 9.*—A part of the polished surface of the transverse section, covered with numerous elongated corrosion-figures running parallel to the sides (010).

*Fig. 10.*—First stage of the alteration of Cordierite, as seen in a microscopic slide taken parallel to the prismatic zone; from the irregular fissures running transversely, begins the deposition of the altered product forming a double layer. From these fissures, the alteration proceeds along the fine canal-like clefts running in a longitudinal direction.  $\times 20$ .

*Fig. 11.*—Microscopic view of the completely altered crystal or Pinite-like pseudomorph from Tamba, cut longitudinally through nearly the middle of the crystal, to show the parallel arrangement of the mica-flakes along the base. Thick black lines and dots are the interpositions of carbonaceous matter, showing the directions of growth at right angles to each other, corresponding to the systems of bundles in Fig. 6. The fine transverse lines are the cleavage traces of the mica flakes.  $\times 20$ .

*Fig. 12.*—Transverse section of the crystal through its middle portion. The three individuals which make up the twin along (110) are widely separated from each other, due to the development of the macropinacoidal faces (100).  $\times 5$ .



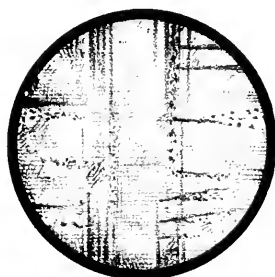


Fig. 11

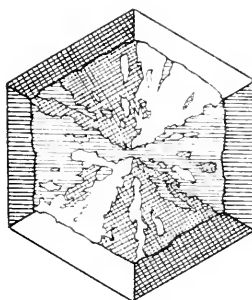


Fig. 3

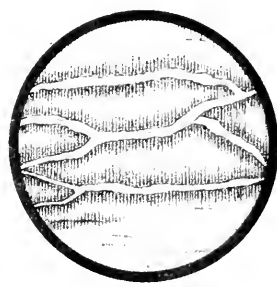


Fig. 10

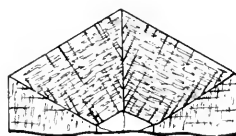


Fig. 9

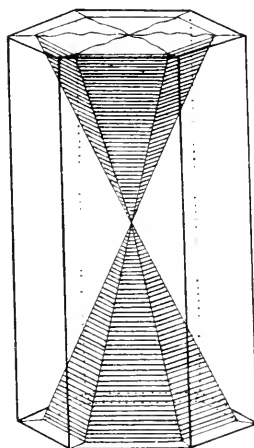


Fig. 2



Fig. 6

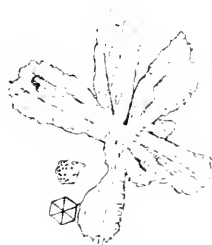


Fig. 8



Fig. 12

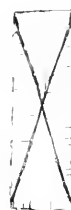


Fig. 5

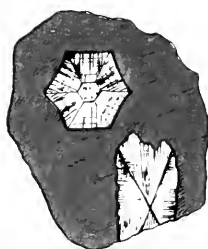


Fig. 7

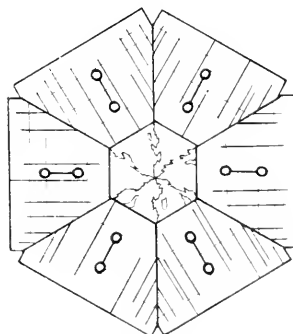


Fig. 1



Fig. 4



# Transient Electric Currents produced by twisting Magnetized Iron, Steel, and Nickel Wires

by

Hantarō Nagaoka.

With Plates XXIX, XXX.

The existence of a transient electric current when a magnetized iron wire is suddenly twisted was first noticed by Matteucci.\* The same subject was afterwards investigated by Professor Ewing,† who examined especially the hysteresis in circular magnetization, when the direction of the magnetizing force was suddenly reversed. He considers the transient current thus developed as an induction current due to acototropic magnetic susceptibility produced in the iron wire by twisting. He also found that the transient current in the twisted wire, produced by reversing the magnetizing current reaches a maximum at a certain strength of the magnetizing force; and that when the field is made greater the current is gradually weakened, but it never changes its direction. I was led to investigate the subject with the aim of tracing some connection between this transient current in nickel and the reversal of polarity in nickel wire in a steady field,‡ when it is under the combined action of torsional and longitudinal stresses. Preliminary experiments were made during the Summer of 1888. My experiments were conducted

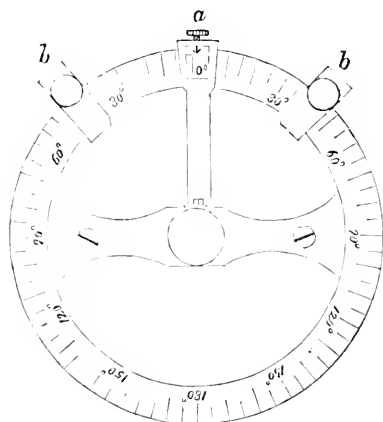
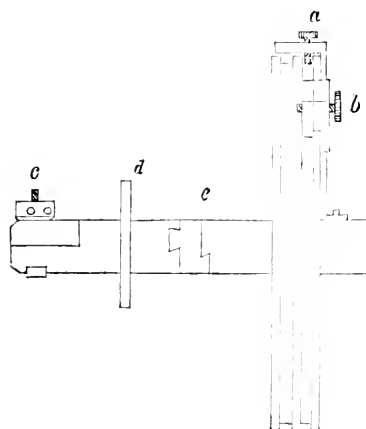
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\* *Annales de Chimie et de Physique*, 1858; or Wiedemann's *Elektricität*, Bd. III.

† *Proc. R. S.* Vol. 36, 1884.

‡ See my previous paper on the combined effect of torsion and longitudinal stress on the magnetization of nickel wire; this *Journal* Vol. II, or *Phil. Mag.* Feb. 1889.

in a manner slightly different from that of Professor Ewing. The wire was suddenly twisted in the magnetizing field, and the quantity of the current thereby produced was measured by means of a ballistic galvanometer. In this way, I found that the direction of the transient current in nickel is opposite to that in iron. Nothing corresponding to the peculiar reversal of polarity was, however, observed. In addition to this, I found that the current in both iron and nickel reaches a maximum for a certain moderate strength of the magnetizing field. In iron, under a constant longitudinal field, there was also a definite angle of twist which gave a maximum current, but in nickel the current always increased with the increase of twist. The fact that the current in nickel is opposite to that in iron has also been independently discovered by Herr L. Zehnder.\* The above experiments of mine are published in *Philosophical Magazine* for January 1890. Resuming the investigation more recently, I examined the transient current in iron, steel, and nickel, either by twisting the wire suddenly, or by reversing the direction of the magnetizing force after the wire had been twisted. Also wires of different diameters were examined.

*Fig. 1.**Fig. 2.*

\* Wiedemann's *Annalen*, Bd. 38. p. 68, 1889.

The twisting apparatus consisted of a graduated circle provided with a small twisting arm (*a*), which can be clamped in any position. (See Fig. 1). A stout brass axis passed through the centre of the circle, and the twisting arm was firmly fixed to it. Round the rim of the graduated circle, two grooves were cut. In one of these, two clamps (*b*) (*b*) were made to slide. These clamps were capable of being fixed in any desired position by means of screws, and served to stop the motion of the twisting arm at the desired angle of twist when the wire was suddenly twisted. The clamp and the grooves are shewn in Fig. 2, which represents the lateral view of the twisting apparatus.

The magnetized wire could not of course be near the galvanometer; and being under the necessity of working alone, I was compelled to use some device for effecting the twist at a distance. For this purpose, two strings were attached to the twisting arm, and made to slide in opposite directions. The strings after passing the groove were made to slide on two pulleys fixed on the table, on which the whole apparatus rested. The axes of these two pulleys were parallel and their planes perpendicular to the face of the circle. The distance between them was equal to the diameter of the circle, and they were fixed in such a position that the strings on leaving the groove and passing down to the pulleys were both vertical. The two clamps (*b*) (*b*) being adjusted so as to stop the twisting arm at the desired positions, the wire was twisted in either direction by simply pulling the proper string. In fact, the mechanism was similar to that of the rudder of a ship.

The wire under examination had its one end clamped to the extremity (*c*) of the axis of the graduated circle, being held in position by pressure sustained by a small nut (*c*), as sufficiently indicated in Fig. 2. Between the clamp and the graduated circle a projecting rim



of circular shape was attached. This dipped in a mercury cup placed underneath, and was in connection with one of the terminals of the galvanometer coil. In order to avoid any induction current that might arise from the sudden motion of the twisting arm and its appendages, that extremity of the axis which served to clamp the wire and lead the current to the galvanometer was insulated, from the rest of the axis and the graduated circle, by a piece of wood (*c*).

The other end of the wire was clamped somewhat similarly on a piece of thick brass plate of rectangular shape, of which the front view is shown in Fig. 3. It was provided with two V shaped projec-

Fig. 3.

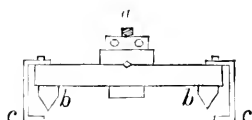
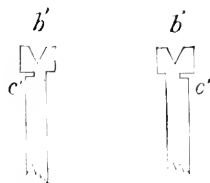


Fig. 4.



tions (*b*) (*b'*), which could slide smoothly on V grooves cut in a brass stand as shown in Fig. 4. The metal plate was prevented from turning over when the wire was twisted, by means of two hooks (*c*) (*c'*), which slid in two grooves (*c'*) (*c*) cut on the lateral sides of the stand. This groove arrangement was necessary when the effect of longitudinal stress was to be studied. The longitudinal stress was applied by hanging a pan of weights to the end of a flexible string which was fastened to the clamping plate and passed over a pulley fixed to the table. The plate was connected with the other terminal of the galvanometer.

The wire to be examined was always well straightened and carefully annealed. When the wire was to be renewed, precaution was taken to cut it always from the same bundle for differences of material necessarily produces difference in the transient current. The wire

was clamped while the pointer of the twisting arm was at zero of the graduated circle. Two clamps were previously fixed on both sides of the twisting arm such that when the wire was twisted in either direction, the arm should stop at the required angle of twist on either side of the initial position of no torsion. The wire was twisted between two extreme limits of twist by pulling the strings attached to the twisting arm in the way before mentioned. When the wire was first twisted, the deflection of the galvanometer magnet was generally large, but after repeated twistings and untwistings, the current settled to its ultimate value, and the reading was then noted.

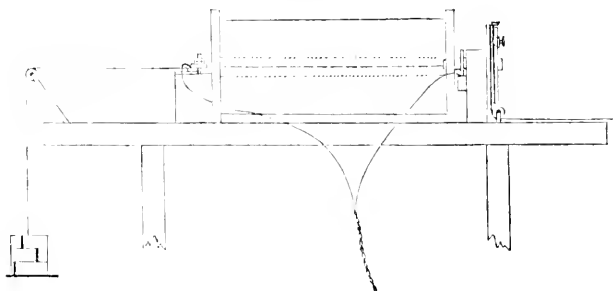
The coil of the low resistance ballistic galvanometer was wound in 20 layers of thick copper wire. It had a resistance of 0.28 ohm. In the core of the coil, a heavy magnet was suspended and the first swing was read by the deflection of a spot of light reflected from a mirror placed outside the coil, but rigidly connected with the magnet. The suspension was similar to that of the ballistic galvanometer made by Siemens and Halske. Since the logarithmic decrement of the vibrating magnet was very small, no correction arising from it was thought necessary, so that the amount of current in the arbitrary scale was taken to be equal to the reading of the first swing. As the moment of the galvanometer magnet is liable to changes especially when the momentary currents are passed through the galvanometer coil, the galvanometer was gauged from time to time by means of an earth inductor.

The magnetizing coil was wound in six layers. The coil was placed on a table due magnetic east and west, and at a distance of nearly 5 metres from the ballistic galvanometer. It was 25 cm. long, and had a resistance of 1.3 ohm. The magnetizing field due to a current of one ampere was 35.5 C. G. S. units. The current was derived from 16 Daniell cells, and its strength was measured by means

of a Thomson Graded Galvanometer. For obtaining strong magnetizing forces, a large coil wound in 12 layers was used with a sufficient number of Bunsen cells.

The arrangement of the coil and the twisting apparatus is shewn in Fig. 5.

*Fig. 5.*



### Transient Current in Iron and Steel.

The transient current produced by twisting an iron wire placed in a magnetizing field has already been studied to a small extent. The results of this earlier investigation have been given in the paper referred to above. The method used in the experiments now to be discussed was different from the earlier method; and in addition, wires of various thickness were examined. The present results are, however, essentially the same, although there are many features which passed unnoticed in the earlier and less detailed experiments.

I shall first of all describe the experiment in the varying magnetizing field, the wire being, in each successive field, twisted to and fro through a given constant angle.

Most of the experiments were made on a soft iron wire, 1.24 mm. thick and 27 cm. long. The wire was carefully annealed, and deprived of residual magnetism by heating it red hot as it lay in a position perpendicular to the magnetic meridian. This precaution is always necessary, for if there remain but a small quantity of residual

magnetism, a transient electric current will be produced, when it is twisted even in zero magnetic field. In fact, one can test whether the wire is completely deprived of magnetism or not, simply by twisting it with its length placed due magnetic east and west, and observing if there exist any transient current or not. The wire thus prepared was placed within the magnetizing solenoid, and suddenly twisted through an angle of  $15^\circ$ . It was then twisted back through zero to an equal angle of twist on the opposite side of zero. The total twisting was therefore through an angle of  $30^\circ$ , namely,  $+15^\circ - (-15^\circ)$ . This twisting I denote as on previous occasions, by  $\pm 15^\circ$ ; and generally the twisting  $\pm \theta$  means a twisting to and fro through an angular range  $2\theta$  about the original position of no twist. Generally the transient current did not settle to a constant value until the wire was twisted several times between the two extreme limits of twist. For each of a series of gradually increasing values of the magnetizing force, the transient current produced by one sudden twisting from limit to limit was measured on the ballistic galvanometer after the system had through repeated to and fro twistings reached a steady cyclic condition. The following are the values in successive fields:—

Magnetizing force.	Transient Current.*
0.7	12
1.7	26
3.2	34
4.5	36
5.8	35
7.5	34
9.8	32
14.6	27
22.6	21
29.0	17
36.7	15

\* One scale division corresponds to  $1.1 \times 10^{-6}$  Coulomb.

Taking for abscissae the strengths of the magnetizing force, and for ordinates the corresponding transient currents, we get the curve (Plate XXIX, Fig I, Curve I) representing the relation between the two.

An examination of the curve will show the changes in the transient current as the strengths of the field is increased. The current at first increases nearly proportional to the increase of the magnetizing force. On passing the field of about 3 units, the increase takes place very slowly and ultimately reaches a maximum for  $\mathfrak{H}=4.5$  nearly. The current then gradually decreases, though at a slower rate than that at which it first increased. This rate of decrease becomes still slower as the field is further increased. The curve representing the relation between the transient current and the strength of the magnetizing force has thus two inflexional points, the one just before reaching the maximum, and the other after passing the maximum. From its similarity to the analogous feature in the curve of magnetization, I shall hereafter call the point at which the ratio of the transient current to the magnetizing force is greatest the 'Wendepunkt' of the transient current curve.

On increasing the angle of twisting to  $\pm 30^\circ$ , and experimenting on a new piece of wire taken from the same bundle and treated in the same way as before, Curve II. Fig. I. was obtained. The examination of this curve shows the same characteristics as before. But the transient current has greatly increased for all strengths of the magnetizing field, while, at the same time, the maximum current occurs in a higher magnetizing field than in the former case. This takes place for  $\mathfrak{H}=6$  nearly.

By increasing the twisting to  $\pm 60^\circ$ , Curve III. was obtained. The changes wrought by this second doubling of the twisting were not nearly so great as in the first doubling from  $15^\circ$  to  $30^\circ$ . The general feature remaining the same as before, we notice a peculiar

difference between the curves II. and III. At first the transient current increases for  $\tau = \pm 60^\circ$  as the field is increased, but until the magnetizing force is about 5 C. G. S. units, the current is always smaller than that for the twisting of  $\pm 30^\circ$ . When  $\mathfrak{H}=5$ , the transient current attains the same value for these two different twists, and henceforth the current for the larger twisting acquires an ascendancy over that for the smaller. The rate of decrease after passing the maximum is slower for the larger twist than for the smaller. The maximum point occurs in a still higher field, namely,  $\mathfrak{H}=8$  nearly.

With the twist increased to  $\pm 90^\circ$ , the transient current curve (IV.) becomes still further transformed. What was noticed on comparing II. with III. applies equally well when we compare III. with IV. The curve in weak fields lies below that for  $\tau = \pm 60^\circ$ , but when  $\mathfrak{H}$  exceeds 13, the former lies above the latter. In this case, however, the maximum current is less for the larger twisting.

From the comparison of these four curves, we may reasonably infer what would be the course of the curve when the angle of twisting is further increased. Evidently the transient current in weak magnetizing fields as well as the amount of maximum current will be smaller for high than for moderate angles of twist. After passing the maximum, the slope of the curve will become less steep, as the angle of twist is increased, so that the curve will necessarily cut all those having a greater maximum current, and ultimately lie above the corresponding branch of the curves for smaller twistings. At the same time, the strength of the magnetizing field corresponding to the maximum transient current will be increased as the twist is taken greater.

The effect of longitudinal stress on the transient current was also tried. It simply produced decrease of the current as I have already mentioned in my former paper.

Professor Ewing has remarked that the production of a transient current by twisting an iron wire in a magnetizing field is a natural consequence of Sir William Thomson's discovery that aeolotropic stress gives rise to aeolotropic magnetic susceptibility in iron. The stress on twisting the wire is equivalent to compression and stretching along lines perpendicular to the radius, and inclined at  $45^\circ$  to the normal plane section. The susceptibility along the lines of compression is different from that in the direction of stretching. The consequence is that the lines of induction originally parallel to the axis of the wire are changed into helices which are inclined toward the direction of the relatively increased magnetic susceptibility. These considerations lead to the conclusion that in nickel, the direction of the current is determined by that of compression while in iron it is determined by that of stretching. Thus the direction of the transient current in iron and nickel should be in opposite directions, and in fact this was found to be the case.

It may, however, be doubted whether the effect of twisting is even approximately equivalent to compression in one direction and extension in the other. It is not at all improbable that twist gives rise to changes in the molecular configuration of the wire. As we are absolutely ignorant of the ultimate structure and arrangement of the molecules, nothing definite can be stated. But if there is any change produced among the polarized molecules of the magnetized wire, it is quite probable that the displacement of the molecules will give rise to changes in the transient current, which will be quite inexplicable in terms of aeolotropic susceptibility as generally assumed. Although such aeolotropy may be one of the chief causes of the transient current, yet other causes may exist whose effects can not be neglected. In fact, I have reason to believe that aeolotropy does not sufficiently explain all the phenomena observed in

iron and nickel, as will be described afterwards.

Considering the results of the preceding experiments, one naturally asks, why does the transient current flow in the direction above specified and why does it reach a maximum? Supposing that anisotropy is the only cause of the transient current, the increase of the current would mean a greater magnetic induction in the direction of stretching than in the direction of compression. The susceptibility of the stretched iron is greater and that of the compressed iron is less than that of iron in an unstrained state, up to a certain critical value of the field. Thus the helices representing the lines of induction would be inclined toward the direction of stretching, and the current must be constantly on the increase until at a certain field the difference of magnetic induction in these two directions begins to diminish. Reasoning in this way, we may explain the general feature of the curve in the following manner.

The amount of compression as well as that of stretching remaining constant throughout the course of experiment, increase of the magnetizing field produces a greater increase of the circular component of the lines of induction in the direction of stretching, than in the direction of compression. The difference in the circular components of magnetization at last reaches a maximum for a certain strength of the magnetizing force. This critical strength of the magnetizing force depends upon the amount of compression and of stretching. In the wire tried above, the position of the maximum is gradually shifted into higher field as the compression as well as stretching is increased, but at the same time, the current does not increase proportionally. There is a certain maximum twisting for which the difference of circular lines of induction in the direction of compression and of stretching reaches the maximum. This seems to occur for the twisting of about  $\pm 60^\circ$  in the wire discussed,



that is, a twist per cm. length of  $\pm 2.^\circ 2$ . When once the maximum difference in the circular lines of induction is reached, the susceptibility in the direction of compression and of stretching gradually tend to equality, so that in strong magnetizing field, the current becomes very small. Subjecting the wire to higher degrees of compression and of stretching makes the difference of susceptibility in strong fields greater, although the maximum difference of susceptibility becomes less after a certain amount of stress is exceeded. Thus it will be seen that the existence of a maximum transient current bears a close relation to the Villari critical point and an analogous point in compressed iron.

Another set of experiments was tried by the following method. Instead of twisting the wire always through the same angle while the magnetizing field was varied the latter was kept constant, while the wire was twisted through angles of twist of gradually increasing amount. For each successive value of twist, the transient

	Curve I.	Curve II.	Curve III.	Curve IV.
$\tau$	$\mathfrak{H} = 2.4$	$\mathfrak{H} = 5.3$	$\mathfrak{H} = 20.7$	$\mathfrak{H} = 58.2$
$5^\circ$	8	3	—	—
$10^\circ$	33	16	12	5
$15^\circ$	46	31	21	—
$20^\circ$	51	46	33	14
$30^\circ$	55	56	44	19
$40^\circ$	54	58	53	24
$50^\circ$	52	59	55	27
$60^\circ$	51	58	57	29
$70^\circ$	51	57	58	30
$80^\circ$	50	57	58	31
$90^\circ$	50	56	57	31

current was obtained and measured exactly as in the previous set of experiments. The wires used in these experiments were in all cases taken from the same bundle, and had a diameter of 1.24 mm. The accompanying table gives the currents in the arbitrary scale unit.

These readings are plotted in Fig. II. (Plate XXIX.), in which the abscissa gives the angle of twisting and the ordinate the corresponding transient current.

In general characteristics all these curves strongly resemble each other. The transient current increases at first very rapidly. Ultimately the current attains its maximum value, and thereafter it begins to decrease very slowly. The general feature of the curves obtained by varying the amount of twisting does not differ much from those obtained by varying the magnetizing force. Each of the curves obtained in both sets of experiments has a maximum point: namely, that corresponding to a particular twist in a constant magnetizing field, or that corresponding to a particular field when the amount of twisting is kept the same. In the latter case, the magnetizing field that gives the maximum current is greater for greater twistings, while in the former the twist giving the maximum current is greater in the stronger field. Although it is difficult to find the particular angle of twisting for which the current attains its maximum value, it can be approximately estimated from the curves plotted in Fig. II. Thus the angles of torsion giving maximum transient currents in different strengths of the magnetizing field come out as follows:—

$\mathfrak{H}$	$\tau$
2.3	$\pm 30^\circ$
5.3	$\pm 50^\circ$
20.7	$\pm 76^\circ$
58.2	$\pm 90^\circ$ (about)

The increase of the angle of torsion giving maximum transient current with the strength of the magnetizing force is thus apparent. We see a strong analogy between the magnetizing force giving maximum current when the twisting is kept constant, and the angle of twisting producing maximum current when the magnetizing force is kept constant; the increase in the one produces increase in the other.

When the wire is subjected to longitudinal stress, the transient current is greatly diminished, while the maximum point occurs for larger twists than in the case of the unstretched wire. In  $\mathfrak{H}=2.4$ , the maximum current occurs for the twist of  $\pm 30^\circ$  when the wire is unloaded; when it is loaded with 4 kg. weight, it occurs at about  $\pm 36^\circ$ , and when the load is increased to 8 kg., it takes place at about  $\pm 42^\circ$  as will be seen from the curves V. and VI. For  $\mathfrak{H}=5.3$ , the angle of torsion giving the maximum transient current is  $\pm 50^\circ$  when the wire is unstrained, but becomes greater than  $\pm 90^\circ$  when the wire is loaded with 8 kg.

If we suppose the development of the transient current to be entirely due to the anisotropic magnetic susceptibility caused by twisting the wire, the transient current in the present set of experiments must depend upon the difference of susceptibilities along the

lines of compression, and the lines of stretching. Taking this as the basis of our reasoning, let us examine what these curves giving the relation between the current and the amount of twisting indicate. The difference of magnetic susceptibilities along lines perpendicular to the radius and inclined at  $45^\circ$  to the normal plane section of the wire increases at first as the wire is subjected to greater twistings. This difference, however, attains a maximum value. Hereafter the susceptibilities along these two lines gradually tend to equality though very slowly as the twisting is taken greater.

Now let us analyze the susceptibilities along the directions of stretching and of compression separately. We know that the susceptibility increases with loading, but when the wire is stretched beyond a certain limit, the susceptibility does not increase any more, and begins to decrease. Although the stretching and compression caused by twisting the wire varies at different distances from the axis of the wire, yet on the whole the increase of twisting necessarily gives rise to increased susceptibility in the direction of stretching until the critical value of stress is reached. It is well known that this critical point occurs with smaller amounts of pulling stress as the magnetizing force is increased. The consequence is that by twisting the wire in strong magnetizing fields, the wire acquires the maximum susceptibility in the direction of stretching for smaller amounts of twisting. Accordingly if stretching was the only stress acting in producing the circular lines of induction which produces the transient current, we should expect to obtain the maximum current at smaller twistings as the magnetizing force is taken greater.

This is contrary to the observed fact, which is that the twisting corresponding to the maximum current is increased with the strength of the magnetizing force. Thus the effect of compression must play an important part in changing the amount of the transient current.

Unfortunately we have not many experimental data on this subject, so full and detailed as those we have on the Villari critical point. According to the experiments of Ewing and Low\*, the effect of compression in altering the susceptibility of iron has a certain similarity to the effect of stretching; and there is a similar reversal corresponding to that of Villari. Under constant compressional stress, the curve of magnetization for compressed iron lies below that for the unstrained, in weak magnetizing fields. In strong magnetizing fields, the former acquires greater susceptibility, and the curve lies above the latter. I do not know of any experiment establishing the relation between susceptibility and the compressional stress, when either the magnetizing force or the amount of compression is made to vary. Without these data, it is difficult to examine the effect on the transient current either by varying the magnetizing force or by varying the amount of twisting.

The fact that compression reduces the susceptibility of iron in weak fields shows why the transient current increases with increase of twist. So long as the magnetizing force does not exceed a certain limit, the susceptibility diminishes in the direction of compression, while it increases in the direction of stretching provided the Villari critical point is not exceeded. Thus the circular component of the lines of magnetic induction is constantly increasing as the twisting is increased and will therefore give rise to an increasing transient current. The increase of current will take place so long as the difference of susceptibilities in these two directions do not diminish. Observation shows that the maximum transient current occurs for larger twistings as the magnetizing force is taken greater. Since the stretching stress giving the maximum susceptibility becomes smaller as the magnetization of the wire is increased, it seems that compression

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\* *Phil. Mag.* 1888.

produces greater diminution of susceptibility as the magnetizing field is taken greater. But consistently with the existence of a point similar to the Villari reversal, and the diminution of magnetization in weak fields, we should find increase of susceptibility in the direction of compression when the magnetizing field is taken sufficiently great. Of course, the increase of susceptibility in a given field will take place only within a certain limit of compressional stress, beyond which there is decrease. If this is really the case, the increase of susceptibility in the direction of stretching must always be greater than the increase in the direction of compression however great the magnetizing field is taken, for otherwise there would be reversal of the direction of current.

Now examining the results of Professor Ewing on the magnetization of soft iron wire, I find that the increase of susceptibility by loading is very small, when the field strength is over 10 units. It is not thus improbable that when the field is taken sufficiently great, the increase of susceptibility in the direction of compression exceeds that in the direction of stretching, so that the current is reversed. But this is quite contrary to the results of the present experiments. On this account, it seems that twisting the wire does not give rise to simple compression and extension along lines inclined at  $45^\circ$  to the normal plane section of the wire and perpendicular to the radius. The molecular arrangement of the wire must also be affected and give rise to additional changes in the transient current, which cannot be ascribed to anisotropy alone.

In the experiments so far described, the wire was always twisted in the magnetizing field between two extreme limits of twist. In the experiments now to be described, the wire after being twisted repeatedly to and fro, was kept in position at either extremity of the range of twist, and the external magnetizing field was then suddenly

reversed in direction. This was done by means of a rocker commutator placed in circuit with the magnetizing solenoid. With the wire kept steadily twisted either on the right or left hand side of the initial position of no torsion after repeated to and fro twistings, a magnetizing force was applied. On reversing the direction of the magnetizing force a momentary current passed through the galvanometer coil. In general the deflection of the galvanometer magnet settled to a constant value after numerous reversals, upon which the swing of the galvanometer magnet corresponding to a reversal was noted. The wire was then twisted in the opposite direction, and after numerous reversals of the magnetizing force, the deflection of the galvanometer magnet was again noted. The mean of these two readings was taken as a measure of the transient current. It should be noted that the direction of the transient current is reversed when either the twist is reversed or the direction of current reversal is changed.

The first set of experiments made in this way was by varying the magnetizing force, the amount of twist remaining constant. The iron wire used was 1.24 mm. thick and 27 cm. long. Instead of giving the observed numbers, I refer to curves plotted in Fig. III. (Plate XXIX.) These show at a glance the relation between the current and the magnetizing force for different amounts of twist. These curves were obtained for the following different angles of torsion.

Curve I for the twist of  $\pm 5^\circ$ ,  
 „ II „ „ „ „  $\pm 15^\circ$ ,  
 „ III „ „ „ „  $\pm 30^\circ$ ,  
 „ IV „ „ „ „  $\pm 60^\circ$ ,  
 „ V „ „ „ „  $\pm 120^\circ$ .

The general feature of all these curves are similar to those obtained by twisting the wire through a given angle in different magnetizing fields. The transient current increases on the application of

an increasing magnetizing force, at first rapidly ; but ultimately the current attains a maximum value. Thereafter it begins to decrease very slowly as the magnetizing force is increased. The transient current in weak field is smaller for large than for moderate twists, but after reaching the maximum, the rate of decrease becomes slower as the twist is taken greater. The consequence is that the curves for larger twists cut the curves for the smaller in a particular magnetizing field. This is well exemplified in the three curves III, IV, and V.

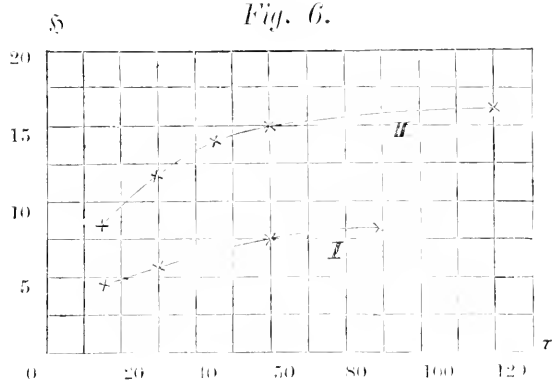
The magnetizing field corresponding to the maximum transient current becomes greater as the amount of twist is increased. The following numbers give the strengths of the magnetizing force corresponding to the maximum transient current.

Angle of torsion.	$\dot{M}$
$\pm 5^\circ$	6
$\pm 15^\circ$	9
$\pm 30^\circ$	12
$\pm 60^\circ$	16
$\pm 120^\circ$	17

The magnetizing field corresponding to the maximum transient current is, however, nearly twice as great when the field is reversed with constant twist than when the twist is suddenly reversed with constant field. The accompanying figure gives the relation between the magnetizing force corresponding to the maximum transient



Fig. 6.



current and the angle of torsion. I. is for the method of sudden twisting, while II. is for the method of sudden reversal.

In the preliminary investigation on this subject, I have already noticed the fact that the magnetizing field giving the maximum transient current by sudden twisting is less than that obtained by Professor Ewing by the method of reversal. I then thought the discrepancy to be probably due to difference of procedure. On experimenting in these two ways with the same wire, I now find that the difference in the position of the maximum is certainly due to the difference in the method. But it seems inexplicable why this should be so, unless the ultimate causes of the transient current are known.

Corresponding to the experiments made by twisting the wire through different ranges in constant magnetizing fields, another set of experiments was tried by reversing the direction of the magnetizing force for different amounts of steady twist. Curves showing the relation between the transient current and the amount of twist are given in Fig. IV. These curves were obtained for the following different strengths of the field.

- |       |     |                              |
|-------|-----|------------------------------|
| Curve | I   | for $S = 1.6$                |
| ..    | II  | .. $S = 5.2$                 |
| ..    | III | .. $S = 8.3$                 |
| ..    | IV  | .. $S = 13.0$                |
| ..    | V   | .. $S = 51.8$                |
| ..    | VI  | .. $S = 51.1$ (loaded 4 kg.) |

Curve VII  $\mathfrak{H}=9.6$  (loaded 4 kg.)

„ VIII  $\mathfrak{H}=5.5$  („ 8 „ ).

These curves, in their chief characteristics, all resemble those obtained by the application of sudden twisting. As the angle of twist is increased, the transient current due to reversal increases at first very rapidly, but ultimately it reaches a maximum whence it begins to decrease slowly. For strong values of the reversing field, the current is small for small twists, but as the twist increases, it ultimately enters the curves for smaller magnetizing force. Thus the rate of decrease of the current for greater twists becomes smaller as the field is increased. So far everything is similar to the results obtained with sudden twisting.

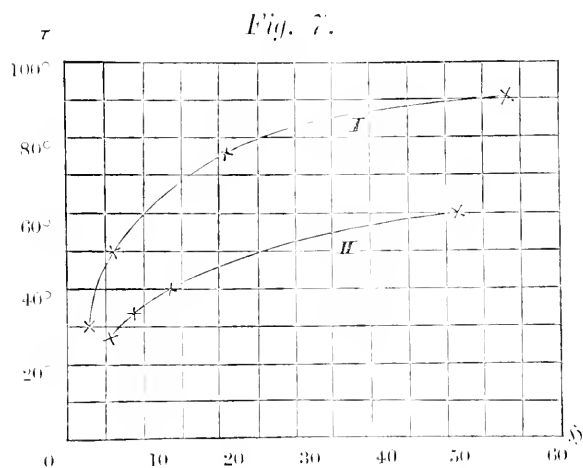
In the curves given in Fig. IV., we again notice the shifting of maximum point to places of greater twist as the magnetizing force is taken greater, as will be seen from the following table.

$\pm \mathfrak{H}$	Twist corresponding to maximum current.
5.2	27°
8.3	31°
13.0	40°
51.8	60°

The twist corresponding to the maximum transient current, whether that is due to reversal of field or to sudden twisting, has a similar relation to the magnetizing force. As the field is increased, the angle of torsion corresponding to the maximum current becomes correspondingly great; but, for the same strength of the magnetizing field, the twist corresponding to the maximum current when the field is reversed is smaller than the twisting of the same name, which for steady field gives the maximum current. Of course the angle of

torsion in these two cases is not strictly comparable, the strain caused by twist or by twisting being somewhat different.

The difference between the two will be seen from the accompany-



ing figure, in which the abscissa gives the magnetizing force and the ordinate represents the twist or twisting corresponding to the maximum transient current. Curve I. is for the method of sudden twisting while II. is for the method of reversal.

If we compare Figs. 6 and 7, we notice that in the latter I. is above II. while in the former II. is above I. This at first sight seems paradoxical, but we see that one is a natural consequence of the other. We saw that for the same angle of torsion, a greater magnetizing force must be applied to make the current attain its maximum strength by the method of reversal than by sudden twisting. Thus it would follow that to make the current reach its maximum value in a given magnetizing field by the former method the amount of twist must be less than the corresponding angle given by the method of sudden twisting. On this account II. lies below I. in Fig. 7.

The strain at any point by twisting the wire depends on the distance of the point from the axis of the wire. All parts of the normal section which are at equal distances from the axis of the wire will be equally strained. Evidently the outer part of the wire must suffer the greater strain. With the same angle of torsion, the strain must be greater in the thick wire than in the thin. Had the

wire been in the form of a thin tube, it would be easy to see how the change in the transient current takes place when the diameter is made to vary. Inside the cylindrical wire, the strain is different in different places, and it is not at all easy to see how the transient current will be altered with the thickness of the wire.

To find how this alteration takes place, wires of different thickness were examined by the method of reversal. These wires were 0.88 mm., 1.24 mm., 1.54 mm., and 2.00 mm. thick respectively. In each case the wire was twisted through  $60^\circ$  in either direction, and the transient current produced in these different specimens by reversing the direction of the magnetizing force was measured. The following table gives the readings.\*

$r=0.44$ (Fig. V, Curve I.)		$r=0.62$ (Fig. V, Curve II.)	
$\delta$	Transient Current.	$\delta$	Transient Current.
3.4	4	1.4	2
6.6	18	3.4	17
11.0	27	6.3	43
16.4	29	9.4	54
21.0	28	13.5	61
24.3	27	16.4	60
28.9	26	20.9	60
37.3	23	29.0	56
		37.4	50

\* In subsequent experiments, one scale division corresponds to  $2.1 \times 10^{-6}$  Coulomb.

$r=0.77$ (Fig. V, Curve III.)		$r=1.00$ (Fig. V, Curve IV.)	
$\delta\dot{N}$	Transient Current.	$\delta\dot{N}$	Transient Current.
1.4	2	1.4	1
4.1	19	4.5	5
6.3	44	7.2	21
9.6	59	10.6	47
12.3	67	13.6	63
16.7	72	16.4	75
21.7	73	20.5	84
24.9	72	28.2	90.5
30.5	69	36.7	90.3
37.0	67		

These readings are plotted in Fig. V. The general appearance of the curve remains the same as was already noticed, but there is gradual transformation of the curve as the thickness of the wire increases. The transient current produced in wires of different thickness varies with the strength of the magnetizing force. In every case, there is an increase of the transient current when the magnetizing force is first increased. The current, however, attains a maximum, and then begins to diminish slowly as in the case of the wire 1.24 mm. thick. With thick wires, the current increases very slowly in weak magnetizing fields, so that the curves for thick wires intersect those for the thin. This effect is very well marked in the thickest wire used. Curve IV. lies below all the rest of the curve so long as the

magnetizing force is not great. In all cases, the maximum transient current is greater as the wire becomes thicker. Thus increasing the diameter of the wire has, to some extent, a similar effect to that produced by increasing the twist in a wire of the same diameter.

When we examine the variation of the maximum position, we notice another feature analogous to that produced by increasing the angle of twist in the same wire. As the diameter of the wire increases, the maximum point is shifted into stronger fields. The following table gives the magnetizing force corresponding to the maximum transient current in wires of different thickness.

For $r=0.44$	$\delta=14.5$
„ $r=0.62$	$\delta=16,$
„ $r=0.77$	$\delta=22,$
„ $r=1.00$	$\delta=30.$

The wires used in the above experiment were of ordinary soft iron. If the quality of iron be different, the transient current curve is somewhat changed. Thus, with a wire of 0.91 mm. radius specially drawn from Swedish iron, the transient current was greater than that obtained with the thickest wire used in the above experiment. The course of the curve is shown in Curve V, Fig. V. In addition to this, the maximum position corresponds to a weaker magnetizing field than it would have done had the wire been of ordinary soft iron. The general feature of the curve, however, does not seem to be greatly affected by the difference in quality.

Another set of experiments was performed by varying the angle of twist while the reversing field was kept constant in magnitude. The wires were taken from the same specimens as used in the above experiments. The magnetizing force was in all cases equal to 19.7. The following table gives the readings, which are plotted in Fig. VI.

	$r=0.44$ (Curve I.)	$r=0.62$ (Curve II.)	$r=0.77$ (Curve III.)	$r=1.00$ (Curve IV.)
$\tau$	Trans. Cur.	Trans. Cur.	Trans. Cur.	Trans. Cur.
5°	8	—	25	32
10°	18	26	47	56
20°	33	48	71	72
30°	42	56	82	88
40°	45	58	88	89
50°	48	60.5	87	84
60°	49.0	61.3	82	80
70°	49.3	60.5	80	78
80°	49.0	59	—	—
90°	48	58	77	—
120°	46	56	76	—

The curves plotted in Fig. VI. have the same appearance as those obtained in similar experiments, by the method of reversal, with wires of the same thickness. For small angles of twist, the current increases very rapidly, but as the twist is further increased, the current attains its maximum value whence it begins to decrease slowly. Examining each curve separately we see that the transient current does not increase in simple proportion to the thickness of the wire. On the contrary, the curves obtained for the wire  $r=1.00$  cuts that for  $r=0.77$  when the twist exceeds  $40^\circ$ . But it follows by no means that the transient current for the thick wire cannot attain still higher values. Looking at Fig. V. we see that  $\S=19.7$  is a little above the point where the curve for  $r=1.00$  crosses the curve for

$r=0.77$ . For the latter, it is near the field giving the maximum transient current. Had the field been stronger, the curve for the thick wire would have lain far above that for the thin wire.

In the preceding experiment, we found that the maximum point of the curve was shifted into stronger fields as the radius of the wire was increased. This shews that if the magnetizing field be kept constant, a large amount of twist must be applied to the thin wire in order to produce the maximum current. The angle of twist corresponding to the maximum current as found from the present set of experiments are as follows :—

For $r=1.00$ ,	angle of twist corresponding to max. cur.=	$36^\circ$
„ $=0.77$ ,	„	$44^\circ$
„ $=0.62$ ,	„	$60^\circ$
„ $=0.44$ ,	„	$72^\circ$ .

Thus the angle of twist at which the maximum current occurs becomes greater as the radius of the wire becomes smaller.

Professor Ewing\* in discussing the apparent discrepancy in the direction of the transient current as obtained by him and by Matteucci attributes it to the fact that in Matteucci's experiments, the amount of twist as well as the magnetization of the iron bar were so great that the Villari critical point had been passed. Unfortunately Matteucci's experiments were performed at a time when the current was not measured in units now in general use. It is now impossible to know the exact value of his magnetizing field; but it is no doubt true, since the iron bars examined by him, were over 5 mm. thick, that the pull and push produced by twisting were very great; and judging from the number of Grove cells he used, the magnetizing field must have been strong. According to the experiments of Professor Ewing, the Villari critical point comes earlier with strong than with weak stresses. Thus it is quite probable that in Matteucci's

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\* *Proc. R. S.*, 1884.



experiments, the critical point may have been passed. But Professor Ewing in discussing the transient current as due to aeolotropic magnetic susceptibility takes the pulling stress only into account, and completely ignores the effect in the direction of compression. As I have already pointed out, compression must play an important part in changing the amount of the transient current. It is the difference of magnetization in the directions of compression and of stretching that gives rise to the transient current, if the phenomena is entirely due to aeolotropic susceptibility. Thus, although the Villari critical point has been passed, the current may flow in the same direction so long as the corresponding compressional stress produces greater decrease of susceptibility than in the direction of stretching. Again the current can reverse its sign even when the Villari critical point has not been passed, provided compression produces greater increase in the magnetism of the iron wire examined. The scantiness of experimental data in this branch of research does not admit us to draw any definite conclusion on the subject under discussion. To see whether the application of very large twist reverses the direction of the transient current, I had recourse to direct experiment rather than to mere reasoning on scanty resources. With this object in view, I subjected an iron wire 1.54 mm. thick, and 27 cm. long to fore and back twistings through an angle of  $360^\circ$ . The twist thus applied amounted to  $13^\circ$  per cm., and must correspond to great compressional and stretching stresses. On reversing the magnetizing current and observing the transient current, it was found that the direction was always the same and determined by the direction of stretching; nor did the current due to this large twist show any notable decrease as compared with currents due to smaller twists as the comparison of the following readings with the same wire for smaller twists will show.

$\delta$	Trans. Cur.
2.0	3
5.7	39
8.9	52
13.0	57
17.3	57.5
19.7	57.5
23.0	57
27.2	56
29.7	54

To study the effect of longitudinal tension upon the current, loads of 4 and 8 kg. were successively applied, and the reading of the galvanometer magnet measured by reversing the magnetizing force. The effect of loading was simply to reduce the current by a small amount, and the representative curves were not greatly altered.

The above result leads me to suspect that possibly Mattenecci made a mistake in determining the direction of the current in relation to the twist and field, always in such experiments somewhat of a confusing matter. The main difference between the experiments of Mattenecci and those of later investigators lay in the thickness of the bar or wire. Mattenecci used mostly an iron bar 6.5 mm. thick, while in the present investigation, the thickest wire experimented on had a diameter of only 2 mm. Accordingly, I determined to repeat the experiment of Mattenecci with a soft iron bar 5.6 mm. thick and 28 cm. long. This was tested both by sudden twisting and by reversing the direction of the magnetizing force. The arrangement for twisting the bar was different from the one described above. It was twisted by means of a lever, into the details of which I need not here enter.

The sudden twisting of the bar produced a large amount of transient current, but the direction of the current was always the same as with wires of smaller diameter. The only difference noticed by twisting the wire was the quantity of the current developed. Nothing differed from the results hitherto described. Professor Ewing has suggested that the twist applied by Matteucci was already beyond the critical value, since the bar was very thick, and that consequently the current must have changed its direction. In the above experiment the bar was twisted through  $90^\circ$  ( $3^\circ$  per cm.). This greatly exceeds the twist applied by Matteucci, his limit being  $20^\circ$  in a bar 60 cm. long, or only  $\frac{1}{3}^\circ$  per cm. We cannot therefore explain the supposed discrepancy in the direction of the transient current as the result of a large twist.

To shew the similarity of the effect obtained with the bar to that obtained with the thin wire, I give the following readings taken in various magnetizing fields by the method of reversal.

$\pm \delta$	Trans. Cur. for $\tau = 30$	$\pm \delta$	Trans. Cur. for $\tau = 60$
3.0	20	2.9	20
6.1	72	5.6	66
9.8	138	8.6	116
12.5	177	11.8	160
16.1	209	15.3	191
21.0	233	18.9	219
24.3	238	22.7	236
30.9	249	27.1	239.5
38.1	231	32.6	239.8
45.4	216	38.8	235
69.4	169	61.4	195
78.9	148	74.8	174

The observations recorded by Matteucci are very few in number. He gives only four galvanometer readings for each experiment. In spite of the scantiness of his data, we can see in a general way what form his transient current curves will have. In all cases, the transient current increases at first with the number of cells used, but always decreases when 10 cells are used. This shows that the transient current curve will have a maximum point, and must be similar in form to those obtained in the experiments described above. From this we may also estimate roughly the strengths of the magnetizing field used by Matteucci. These facts indicate that the direction of the current as stated by Matteucci, if not an accidental mistake, must be due to some other cause than that suggested by Professor Ewing.

The transient current developed in twisted steel wires was examined by the method of reversal, as was done for iron. The wire was twisted through  $\pm 60^\circ$ , and the strength of the magnetizing force gradually increased. The direction of the magnetizing current was reversed, and the reading of the galvanometer magnet was noted. Two specimens of steel wires were examined. The one had a diameter of 1.28 mm., and the other 1.50 mm. Plotting the readings on the galvanometer scale, Fig. VII. was obtained. The current increases as the magnetizing force is increased. Ultimately it reaches a maximum, and then gradually begins to diminish. The transient current flows in the same direction as in iron. The only differences, which will be apparent at a glance, are the comparative smallness of the current and the higher magnetizing force corresponding to the maximum transient current. For wires of nearly the same thickness, the transient current in steel does not amount to more than a fourth part of that in iron. On the other hand, the maximum current in steel occurs in a stronger magnetizing field than in iron, as the comparison of the curves represented in Figs. V. and VII. will show.

With varying twists in a constant field of 20 C. G. S. units, Curves I., II., III. in Fig. VIII. were obtained with three specimens of steel wires of different gauge. Their diameters were 1.26 mm., 1.50 mm., and 1.82 mm. respectively. The readings are as follows:—

	$r=0.63$ (Curve I.)	$r=0.75$ (Curve II.)	$r=0.91$ (Curve III.)
$\tau$	Trans. Cur.	Trans. Cur.	Trans. Cur.
$5^\circ$	1	—	—
$10^\circ$	3	5	9
$20^\circ$	7	11	14
$30^\circ$	10	14	19.5
$40^\circ$	15	17.8	21.3
$50^\circ$	16.5	18.3	20
$60^\circ$	16.8	17.0	18.5
$70^\circ$	15.8	16	18.0
$80^\circ$	15.0	15	
$90^\circ$	14.3		

In these three curves, we notice the same characteristics as have been already noticed in similar experiments with iron. There is a certain angle of twist for which the transient current is a maximum. This angle of twist varies with the thickness of the wire, and is smaller for the thick than for the thin wire. Thus the currents in iron and steel are in every respect similar, except in the amount of the transient current developed and the position of the maximum current.

When soft iron or nickel wire is twisted it immediately acquires a large permanent set, and would in no case return to the initial position of no torsion. In steel, the limit of elasticity is very great compared with soft iron or nickel. Whenever the steel wire is twisted and afterwards released, the wire almost always returns to its former position although the amount of twist is considerable. The

smallness of the current in steel indicates that the stress produced by twist has a smaller effect in steel than in iron. The principal point of difference in these two substances is at the same time attended with a difference in the permanent set acquired by the twisted wires. These facts suggest that there exist certain intimate relations between the transient current and the limit of elasticity.

### Transient Current in Nickel.

As I have already remarked, the present investigation originated in searching if the transient current does not show any peculiarity in the magnetized nickel wire, which has undergone the reversal of polarity by the combined action of torsion and longitudinal stress. With this object in view, the transient current produced by twisting the nickel wire was examined under different longitudinal stresses, the strength of the magnetizing field being made to vary. No peculiarity occurring simultaneously with the reversal of polarity was observed. A more minute study was then instituted, in which the nickel wires were subjected to the same treatment as the iron and steel wires.

The arrangement for twisting the wire, and the method of measuring the transient current, were exactly the same as in the experiment with iron, so that the further description of the process will be unnecessary here.

Two specimens of nickel wires were specially examined. The one was 0.5 mm., and the other 0.43 mm. in radius. The wire was carefully annealed, and deprived of residual magnetism by heating it red hot. This precaution was especially necessary with the nickel wire, for if there remained but a small quantity of the residual magnetism, quite a large amount of transient current was produced. As in the case of iron, the current did not attain its ultimate value

until the wire was subjected to many back and fore twistings. The following table gives the reading of the swing of the ballistic galvanometer magnet, obtained by twisting the wire 1 mm. thick and 27 cm. long, through different angles, while the magnetizing force was made to vary.

$\tau = \pm 30^\circ$		$\tau = \pm 45^\circ$		$\tau = \pm 60^\circ$		$\tau = \pm 90^\circ$	
$\S$	Trans. Cur.	$\S$	Trans. Cur.	$\S$	Trans. Cur.	$\S$	Trans. Cur.
3.9	67.5	2.3	69.6	1.2	63.3	0.6	60.0
6.7	70.8	4.4	74.6	3.8	75.8	2.0	73.6
10.1	71.7	8.5	75.9	7.1	78.6	4.5	76.7
14.1	73.1	13.3	77.3	9.3	79.8	7.2	79.0
17.0	73.6	21.0	77.1	13.9	79.8	9.4	79.8
23.6	73.6	30.2	76.9	21.1	78.6	13.6	80.5
32.3	72.5	48.5	75.5	39.6	78.2	16.5	80.5
53.7	70.0			54.1	77.1	23.0	79.8
65.5	68.9					28.6	79.7
						30.8	79.0

These readings express the quantity of transient current in the same scale unit as used formerly in similar experiments with the iron wire of 0.62 mm. radius. These readings are plotted against the corresponding magnetizing force in Plate XXX, Fig. IX. Curves I., II., III., IV. Two dotted curves V. and VI. were obtained from experiments made on thin nickel.

The above table shows that the rate of increase of the current when the magnetizing force is first applied is enormous. The curve

rises nearly perpendicular to the axis of  $\mathfrak{N}$ . This rapid increase, however, takes place only within a small range of the magnetizing force. After a certain strength of field is reached, which in the above experiment does not exceed 5 units, the curve reaches the wendepunkt. After passing this point, the curve rises very little, the current remaining of nearly the same strength within a pretty large range of the magnetizing field. There is, however, a maximum, as will be seen by examining the readings. But as the decrease of the current after as well as its increase before the maximum is reached takes place very slowly, it is difficult to know the exact strength of the magnetizing force corresponding to the maximum. The curve representing the transient current is somewhat similar to the curves of magnetization of twisted nickel wire, with the difference that in the latter there is no maximum point.

The examination of these curves shews that there is no great variation of current with the difference of the angle of twist, so that among the four curves taken with 1 mm. wire, we notice only small displacement of curves for larger twistings. Nevertheless, the current is sensibly smaller for the smaller twistings. Nothing definite can be said as to any change of the magnetizing force corresponding to the maximum transient current as the twist is increased. One thing, however, is quite certain—the magnetizing field corresponding to the maximum transient current is generally greater in nickel than in iron.

Another remarkable difference in the currents produced in iron and in nickel is the oppositeness of the direction of the transient current. The direction of the current in iron is from the north to the south pole when the wire is twisted right-handedly, whereas in nickel it is from the south to the north pole. If we consider the current as the effect of acolotropic stress produced by twisting, the current in



nickel is determined by the direction of the spiral of compression. Sir William Thomson described these phenomena in the following language.\*

“To avoid circumlocutions suppose the iron or nickel wire to be vertical, and the magnetizing current to be in the opposite direction to that of the motions of the hands of a watch held with its face up. The undisturbed magnetization is downwards. Now suppose a right-handed twist to be given to the wire. Its elongational spiral is right-handed, and its contractional spiral is left-handed. If the substance is iron, the lines of magnetization become left-handed spirals; if nickel, right-handed. Now a downward current, in the downwardly magnetized wire, would, by the superposition of circular magnetization in the direction opposite to that of the hands of a watch, cause the lines of magnetization to become left-handed spirals. Hence the sudden right-handed twist induces in iron a current upwards, in nickel a current downwards. Thus we have the following simple specification for the directions of the induced longitudinal currents in the two substances, without reference to “up” and “down.”

“From any point, P, on the surface of the wire draw samewards parallels to the current in the nearest part of the magnetizing solenoid, and to the direction of the induced longitudinal current. Draw a helix through P making an acute angle with each of these lines. This helix is of same name as the elongational helix for iron, and as the contractional helix for nickel.”

Another set of experiments was tried by twisting the nickel wire in a constant magnetizing field, different amounts of twist being taken in succession. The results are shown graphically in Fig. X.

For the wire of 0.5 mm. radius:—

Curve I. for  $S = 5.0$

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\* See note to my former paper, *Phil. Mag.*, Jan. 1890.

Curve II. for  $\xi = 9.8$

„ III. „ „  $= 10.5$  (loaded 5 kg.)

„ IV. „ „  $= 9.8$  (loaded 8 kg.)

For the wire of 0.43 mm. radius:—

Curve V. for  $\xi = 32.8$

„ VI. „ „  $= 9.9$  (loaded 8 kg.)

For wires under no longitudinal stress, the current increases as the twist is increased. The rate of increase is at first very rapid, but the curves always show a *wendepunkt* beyond which the increase takes place only very slowly, up to the greatest amount of twist applied in the present experiment. The current increases with the twisting for all strengths of the magnetizing force, but in all cases the increase of the current beyond a certain angle of twist takes place so slowly that the curve seems to be nearly parallel to the horizontal axis.

When the nickel wire is loaded, the effect of increasing the angle of twist is somewhat different from what occurs under no longitudinal stress. The current reaches the maximum value at a certain angle of twist, and then begins to decrease as will be seen from curves III. and IV. With wires 0.86 mm. thick, no such maximum was noticed.

The stress produced by twisting the nickel wire is a combination of compression and stretching as in the case of iron. The magnetic susceptibility of nickel in the direction of contraction is always decreasing as the twist is increased, and that in the direction of compression is always increasing. Thus the component of circular magnetization will be in the direction of compression. Moreover the circular magnetization is always increasing as the amount of twist is made to increase. This increase, however, takes place very slowly beyond a certain angle of twist, for when the stretching and the

compressional stresses are increased, the change in magnetization in both directions becomes very small. In fact, we should expect the transient current to increase with the twisting, and to have no maximum if the current be due simply to aeolotropy. The preceding experiments in constant magnetizing field show that this is really the case. On the other hand, when the magnetizing field is made to vary, the current reaches a maximum. Looked at from the point of view of aeolotropy, this would mean that the arithmetical sum of the increase of the magnetization in the direction of compression and the decrease of magnetization in the direction of stretching reaches a maximum value at a certain magnetizing field, a conclusion which agrees with the experiments of Ewing. Thus aeolotropic magnetic susceptibility in the directions of stretching and of compression not only explains the direction of the current, but also some of its general characteristics.

The transient current produced by reversing the direction of the magnetizing force was examined in the same manner as in the case of iron. With the wire kept twisted, the magnetizing force was reversed many times, and immediately thereafter, the reading of the first swing due to the next reversal was taken. This was done with a series of gradually increasing values of the magnetizing force. Out of numerous experiments, I give only five of the curves (Fig. XI) taken with the thick wire and four (Fig. XII) obtained with the thin.

For the thick wire:—

- Curve I. for  $\tau = \pm 30^\circ$
- .. II. ..  $\tau = \pm 90^\circ$
- .. III. ..  $\tau = \pm 180^\circ$
- .. IV. ..  $\tau = \pm 60^\circ$  (loaded 4 kg.)
- .. V. ..  $\tau = \pm 60^\circ$  ( .. 8 kg.)

For the thin wire:—

- Curve I. for  $\tau = \pm 60^\circ$   
 „ II. „  $\tau = \pm 360^\circ$   
 „ III. „  $\tau = \pm 60^\circ$  (loaded 4 kg.)  
 „ IV. „  $\tau = \pm 60^\circ$  („ 8 kg.)

The principal features of all these curves are nearly the same in all cases, and resemble those for iron. The first application of the magnetizing force makes the current increase very rapidly. This increase, however, takes place only within a small range of the magnetizing force. The curve soon reaches the wendepunkt, and thereafter goes on rising very slowly. In the first two curves in Fig. XI. the magnetizing force was not sufficient to make the current reach its maximum value. In the third experiment for  $\tau = \pm 180^\circ$ , stronger magnetizing forces were applied, and then the existence of the maximum was demonstrated. The following are the readings.

$\mathfrak{H}$	Trans. Cur.
3.7	3.8
5.1	15.3
7.6	38.0
9.5	48.4
12.6	56.1
16.5	59.9
20.7	64.3
34.1	67.4
50.6	67.4
78.6	66.9

As was remarked before for iron wires, the maximum transient current produced by reversing the direction of the magnetizing force occurs for higher values of the magnetizing force than is the case when the wire is suddenly twisted in a steady field. The comparison

of curve III. Fig. XI. with any one given in Fig. IX. will show that this must also be the case with nickel.

Another point of difference between these two methods is the difference in the position of the wendepunkt, and the initial form of the curve before reaching the wendepunkt. In the experiments made by sudden twisting, the wendepunkt occurs in weaker magnetizing fields as the twist is increased; but it is otherwise when the magnetizing force is reversed. In this case, the wendepunkt gradually shifts into higher regions of the magnetizing field. The first increase of the *twisting* transient current, as the magnetizing force is increased, takes place more rapidly for greater twistings; but when the direction of the magnetizing force is reversed, the same increase takes place more rapidly for the smaller twist. This fact is evident from the examination of the curves I., II., III. in Fig. IX. and I., II. in Fig. XI. The curve for  $\tau = \pm 90^\circ$  lies at first below the curve for  $\tau = \pm 30^\circ$ , while the curve for  $\tau = \pm 180^\circ$  lies, at the outset, below the curves for these other angles of twist.

When the wire is subjected to longitudinal stress, the curve undergoes a slight alteration. The initial part of the curve lies below the curve for the unloaded wire, but the current increases steadily, and finally reaches the wendepunkt, which occurs at a higher field than in the case of wires under no longitudinal stress. As the longitudinal stress is increased, the current becomes smaller in weak magnetizing fields, but it increases steadily with the increase of the magnetizing force so that the curve ultimately cuts the curve for no longitudinal stress. At the same time the wendepunkt of the curve is shifted into stronger fields. Similar results have been obtained for the twisting transient current.

In the experiment made by suddenly twisting the nickel wire, it was seen that with the angle of twist then applied, the current was

always increasing as the twist was increased. This is in harmony with the view of aeolotropic magnetic susceptibility. In the experiments now to be described, the same series of experiments were performed by subjecting the twisted wire to reversals of the magnetizing forces. The results thus obtained are somewhat striking, and seem incapable of explanation in terms of aeolotropic magnetic susceptibility.

The experiment was tried in exactly the same way as for iron. Out of a number of experiments made in this way, I give the following, as showing the typical relation between the amount of twist and the transient current.

The following are the readings made with the thick wire; and the corresponding curves are shown in Fig. XIII.

	Curve I.	Curve II.	Curve III.
$\tau$	$\mathfrak{H}=10.6, w=0.$	$\mathfrak{H}=4.5, w=5 \text{ kg.}$	$\mathfrak{H}=9.8, w=5 \text{ kg.}$
$10^\circ$	—	3	16
$20^\circ$	21	13	50
$30^\circ$	44	27	68
$40^\circ$	63	38	74
$50^\circ$	65	44	77
$60^\circ$	64	43	75
$70^\circ$	62	37	72
$80^\circ$	59	23	71
$90^\circ$	57	2.3	69
$100^\circ$	52	1	63
$120^\circ$	44	0	56
$140^\circ$	38	0	(150°) 47
$180^\circ$	18		41
$270^\circ$	7		
$360^\circ$	3		
$450^\circ$	2		
$540^\circ$	1.5		

The following give the observations made with the thin wire.

	Curve IV.	Curve V.	Curve VI.
$\tau$	$\mathcal{N}=9.8, W=0.$	$\mathcal{N}=5.0, W=5.$	$\mathcal{N}=25.1, W=5.$
10°	25	2	30
20°	44	—	59
30°	52	19	66
40°	56	20.5	64
50°	56	6.5	63
60°	57	4.0	62
70°	56	—	61
80°	55	2.8	61
90°	54	—	60
120°	52	0.5	—
150°	50		58
180°	47		56
360°	30		50

On the first application of twist, the transient current increases with the angle of twist, but it soon reaches the wendepunkt and very quickly thereafter a maximum. The curve then dips, and the decrease of current with the increase of twist takes place nearly proportional to each other, so that the curve appears to be nearly straight. But there is another point of inflexion (not shown in the figure, but evident from the readings). Thence the curve dips very slowly, and ultimately becomes asymptotic to the line of no transient current. The current is very small when the twist is large, but from the course of the curve it is evident that further twistings will not reverse the direction of the current.

The curve undergoes great deformation when the wire is subjected to longitudinal stress, especially when the magnetizing force is weak. The initial rise of the current takes place in the same way as represented by curves obtained with unstrained wires. The curve

after passing the maximum dips very rapidly describing a curve which is more curved than that for the unloaded wire. The current decreases very rapidly, so that it is soon reduced to a very small amount. Thus after the angle of torsion exceeds  $90^\circ$  or thereabouts, the deflection of the galvanometer magnet produced by reversing the direction of the magnetizing force is scarcely appreciable. On greatly increasing the twist, the transient current remains in the same state, so that it is quite probable that the current ultimately becomes vanishingly small when the twist is very great, but the direction of the current will never become reversed. Curves II. and V. show these features very distinctly.

It must not be supposed that a similar curious change takes place in the transient current whenever the wire is loaded. It is only in weak magnetizing fields that the changes above described take place. On examining the transient current in  $\mathfrak{H}=10.6$  with the thick wire subjected to a longitudinal stress of 5 kg. weight, Curve III. was obtained. The course of the curve is slightly different from that obtained with the unloaded wire in  $\mathfrak{H}=9.8$  (see Curve I.). The maximum point is present for nearly the same angle of twist, both for the loaded and for the unloaded wire. The curve dips after passing the maximum, but the course is nearly straight and not curved as in II. and V., so that the transient current will be appreciable unless the twist becomes very great.

According to the researches of Professor Ewing, longitudinal stress always decreases the magnetic susceptibility of nickel, while compression always increases it. If we resolve the torsional stress, as has already been done into extension and compression at right angles to the radius of the wire, and inclined at  $45^\circ$  to the plane section normal to the axis, the circular component of the lines of induction will be constantly on the increase as the twist is taken greater. If,



then, we are to explain the transient current in terms of known changes of susceptibility in the directions of elongation and compression, we should expect the circular components of the lines of induction in the wire, and probably the transient current, to increase as the twist is increased. But in the experiments just described, there is a maximum which comes with a tolerably small amount of twist, and there is always decrease of current when the angle of twist becomes sufficiently great. These results on the transient current, and the change of susceptibility in the directions of compression and of stretching lead to contradictory conclusions. Thus it seems that the peculiarities of the transient current cannot be explained in terms of anisotropic susceptibility, but some other causes must be acting in producing the peculiarity mentioned above.

In order to find how the transient current is affected by the thickness of the wire, four specimens of nickel wire were examined by the method of reversal. The angle of twist was in all cases equal to  $\pm 60^\circ$ . The following table gives the readings;\* the curves are shown in Fig. XIV.

$r = 0.5$ (Curve I.)		$r = 0.65$ (Curve II.)	
$\Sigma$	Trans. Cur.	$\Sigma$	Trans. Cur.
1.5	3	3.5	21
3.8	8	7.6	55
5.8	21	12.2	63
7.6	32	17.7	65
11.4	39	22.7	65
14.8	41	27.7	66.3
18.2	42.8	33.5	66.8
20.4	43.3	41.9	66.5
23.6	43.5	50.6	66
27.8	43.5	66.6	64
33.8	43.3	117.0	57.
44.9	42.8		

\* One scale division corresponds to  $2.1 \times 10^{-6}$  Coulomb.

$r=0.84$ (Curve III.)		$r=1.00$ (Curve IV.)		$r=0.65$ (Curve V.) w=5 kg.	
$\mathfrak{H}$	Trans. Cnr.	$\mathfrak{H}$	Trans. Cur.	$\mathfrak{H}$	Trans. Cur.
1.5	3	3.5	1	3.5	4
3.5	53	7.2	76	7.5	50
6.7	71	13.1	106	12.2	65
9.0	80	17.7	108	15.5	67
11.4	83	22.6	114	22.0	71
14.7	87	31.8	116	29.2	71.8
18.1	88	39.4	121	37.6	72.3
20.4	88	50.3	118	49.8	71
23.4	89	83.0	114	76.7	69.
27.8	89	125.1	108		
34.0	90				
45.6	88				

These curves for wires of different thickness, have all the same characteristics as already noticed. The current, after reaching the wendepunkt, increases so slowly that it is difficult to tell where the curve reaches a maximum. Nevertheless, as will be seen from the readings, the transient current for each of these wires does reach a maximum, which seems to occur at lower fields in the thinner wire. The curves for nickel are similar to those obtained with iron wires, the only points of difference between the two being the indistinctness of the maximum point in nickel and its occurrence in higher fields. On stretching the wire longitudinally, the same effect as already described in similar experiment by the method of sudden twisting was obtained. In weak magnetizing fields, the current produced in the loaded wire is less than in the unloaded. But near the wendepunkt, the curve for the loaded wire passes above the unloaded, and beyond this point the current for the former becomes always greater than

that for the latter. Moreover the maximum for the loaded wire takes place in stronger field than for the unloaded.

Corresponding to the above, another set of experiments was performed by the method of reversal, the strength of the field being kept equal to 19.7 throughout the course of experiment and the twists being varied. The following are the readings; the curves being shown in Fig. XV.

	$r=0.5$ (Curve I.)	$r=0.65$ (Curve II.)	$r=0.84$ (Curve III.)	$r=1.00$ (Curve IV.)
$\tau$	Trans. Cur.	Trans. Cur.	Trans. Cur.	Trans. Cur.
5°	9	18	34	34
10°	16	31	51	62
20°	26	47	65	82
30°	30	52	71	85.0
40°	33	51	71	84.8
50°	33	51	69	83.8
60°	34	53	67.3	83
70°	34	52.5	67	82
80°	34	52.3	66.8	81
90°	34	—		
100°	33	51.8		
120°	33	51.		

The examination of these curves shows the increase of the transient current when the diameter of the wire becomes greater. As I have already noticed before, the transient current always reaches its maximum value for a certain angle of twist. The angle giving maximum current varies with the thickness of the wire. The thicker the wire, the smaller the amount of twist which is to be applied to make the current arrive at a maximum, as will be seen from the following:

for $r=0.50$	$\tau = 70^\circ$ ,
„ $r=0.65$	$\tau = 45^\circ$ ,
„ $r=0.84$	$\tau = 36^\circ$ ,
„ $r=1.00$	$\tau = 30^\circ$ .

The curves also resemble those obtained in similar experiments with iron.

When the nickel wire is loaded and then subjected to varying twists, the curves of transient current present a peculiar aspect, especially when the field is weak. To test this for thick wires, experiments were performed with wires 1.68 mm. and 2.00 mm. thick respectively. The curves (see Fig. XVI.) thus obtained show the same characteristics as before noticed. After passing the maximum point, the decrease of the transient current takes place very rapidly. The current, a little while after, becomes insignificantly small, so that for large twists, it is insensible to the galvanometer. Thus the peculiarity seems not to be due to the thickness of the wire.

In my former paper, I had occasion to remark that the transient current curve resembles the curve of the Wiedemann effect. In the latter, the twist due to superposed circular and longitudinal magnetization of the wire increases at first with increase of the magnetizing force, but ultimately reaches a maximum. According to the researches of Professor Knott, the twist in nickel takes place in the opposite sense to that in iron, and the maximum twist in the former occurs in much higher magnetizing fields than in the latter. These facts are in every way similar to those observed in the transient current. Following the close analogy between the Wiedemann effect and the transient current, experiments were made in order to find if the similarity can be pushed even to very strong magnetizing fields. According to Mr. Bidwell, the Wiedemann effect in iron is reversed when

the magnetizing force is sufficiently great. If the similarity exists, there should be a reversal in the direction of the transient current. With the strongest magnetizing current at my disposal ( $\mathfrak{H}=500$ ) no reversal of the transient current was noticed. The analogy thus seems to fail in very strong magnetizing fields.

The following gives the summary of the results obtained in the present investigation.

- 1.—The transient current produced by suddenly twisting the iron wire, or by reversing the direction of the magnetizing force while the wire is held twisted, through a constant angle, increases as the field is increased, but after reaching a wendepunkt, it soon arrives at a maximum point, whence it begins to decrease slowly as the field is further increased.
- 2.—The rise of the transient current in gradually increasing fields is smaller for large than for moderate angles of twist, but in strong magnetizing fields, the current becomes greater as the twist is taken larger.
- 3.—The maximum point varies with the amount of twist, and occurs in higher fields as the twist is taken larger.
- 4.—The transient current in stretched iron wire is less than that in the unstretched.
- 5.—The transient current produced in a constant magnetizing field by varying the amount of twist increases at first with the increase of twist. The current, however, arrives at a maximum point, whence it begins to decrease slowly as the twist is increased.
- 6.—The initial rise of the transient current as the twist is increased is greater in weak than in strong fields.
- 7.—The maximum point varies with the strength of the magnetizing force, and occurs for larger twists as the field is stronger. The twist corresponding to the maximum current is smaller by the method

of reversal than by sudden twisting.

- 8.—When the thickness of the wire is altered, the initial rise of the current with the increase of the magnetizing force is greater as the wire becomes thinner, but the maximum current and the magnetizing force giving the maximum current both increase with the thickness of the wire.
- 9.—When the twist is varied in a constant magnetizing field, the maximum point occurs for smaller twists as the thickness of the wire is increased.
- 10.—Everything with regard to the transient current in steel is similar to that in iron, with the exception, that the current is smaller, and the magnetizing force corresponding to the maximum current is stronger, than those observed in iron wires of the same thickness.
- 11.—The transient current produced by twisting nickel wire, or by reversing the direction of the magnetizing force is opposite in direction to that in iron. The wire being twisted into a right-handed screw, the current in nickel flows from the south to the north pole.
- 12.—The transient current produced by twisting, or by reversing the direction of the magnetizing force while the wire is held twisted, soon arrives at a *wendepunkt*, beyond which the increase takes place very slowly, and ultimately attains a maximum. The decrease with further increase of the magnetizing force is very slow. The *wendepunkt*, for the same angle of torsion, comes sooner by sudden twisting than by the method of reversal.
- 13.—The current in weak fields is smaller when the wire is loaded, but in strong fields the curve of transient current passes above that for the unloaded.
- 14.—With the magnetizing force constant, and the amount of twist variable, the transient current produced by sudden twisting always increases as the twisting is increased. The increase, however, takes

place very slowly beyond a certain angle of twist.

- 15.—Everything being the same as in (14), the transient current produced by reversing the direction of the magnetizing force increases at first with the increase of twist, but it soon reaches a maximum. After this a slow decrease of the current takes place, and when the twist is very large, the current becomes very small.
- 16.—Loading the wire and proceeding in the same way as in (15), the current decreases rapidly after passing the maximum, and soon after becomes very small.
- 17.—When the thickness of the wire is different, the transient current is in general greater as the wire becomes thicker. The current in weak fields is smaller with the thick than with the thin. The maximum current occurs in higher magnetizing field as the thickness is increased.
- 18.—With the magnetizing force constant, and the amount of twist variable, the maximum current occurs for smaller twists as the wire becomes thicker.



PLATE XXIX.



## Plate XXIX.

*Fig. I.*—Obtained by twisting iron wire ( $r = 0.62$ ) in varying magnetizing fields.

Curve I. for $\tau = \pm 15^\circ$ ;	Curve II. for $\tau = \pm 30^\circ$ ;
„ III. „ $\tau = \pm 60^\circ$ ;	„ IV. „ $\tau = \pm 90^\circ$ .

*Fig. II.*—Obtained by twisting iron wire ( $r = 0.62$ ),  $\tau$  being variable.

Curve I. for $\delta = 2.3$ ;	Curve II. for $\delta = 5.3$ ;
„ III. „ $\delta = 20.7$ ;	„ IV. „ $\delta = 58.2$ ;
„ V. „ $\delta = 2.4, w = 4 \text{ kg.}$ ;	„ VI. „ $\delta = 2.4, w = 8 \text{ kg.}$ ;
„ VII. „ $\delta = 5.3, w = 8 \text{ kg.}$	

*Fig. III.*—Obtained by reversing the direction of the magnetizing force with iron wire ( $r = 0.62$ ),  $\delta$  being variable.

Curve I. for $\tau = \pm 5^\circ$ ;	Curve II. for $\tau = \pm 15^\circ$ ;
„ III. „ $\tau = \pm 30^\circ$ ;	„ IV. „ $\tau = \pm 60^\circ$ ;
„ V. „ $\tau = \pm 120^\circ$ .	

*Fig. IV.*—Obtained by reversal with iron wire ( $r = 0.62$ ),  $\tau$  being variable.

Curve I. for $\delta = \pm 1.6$ ;	Curve II. for $\delta = \pm 5.2$ ;
„ III. „ $\delta = \pm 8.2$ ;	„ IV. „ $\delta = \pm 13.0$ ;
„ V. „ $\delta = \pm 51.8$ ;	„ VI. „ $\delta = \pm 5.1, w = 4 \text{ kg.}$
„ VII. „ $\delta = \pm 9.6$ ;	„ VIII. „ $\delta = \pm 5.5, w = 8 \text{ kg.}$

*Fig. V.*—Obtained by reversal for  $\tau = \pm 60^\circ$  with different wires,  $\delta$  being variable.

Curve I. for $r = 0.44$ ;	Curve II. for $r = 0.62$ ;
„ III. „ $r = 0.77$ ;	„ IV. „ $r = 1.00$ ;
„ V. „ $r = 0.91$ , (Swedish iron).	

*Fig. VI.*—Obtained by reversal in  $\delta = \pm 19.7$  with different wires,  $\tau$  being variable.

Curve I. for $r = 0.44$ ;	Curve II. for $r = 0.62$ ;
„ III. „ $r = 0.77$ ;	„ IV. for $r = 1.00$ .

*Fig. VII.*—Obtained by reversal with steel wires,  $\delta$  being variable.

Curve I. for $r = 0.63, \tau = \pm 60^\circ$ ;	Curve II. for $r = 0.91, \tau = \pm 60^\circ$ .
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*Fig. VIII.*—Obtained by reversal with steel wires,  $\tau$  being variable.

Curve I. for $r = 0.63, \delta = 19.7$ ;	Curve II. for $r = 0.75, \delta = 19.7$ ;
„ III. „ $r = 0.91, \delta = 19.7$ .	

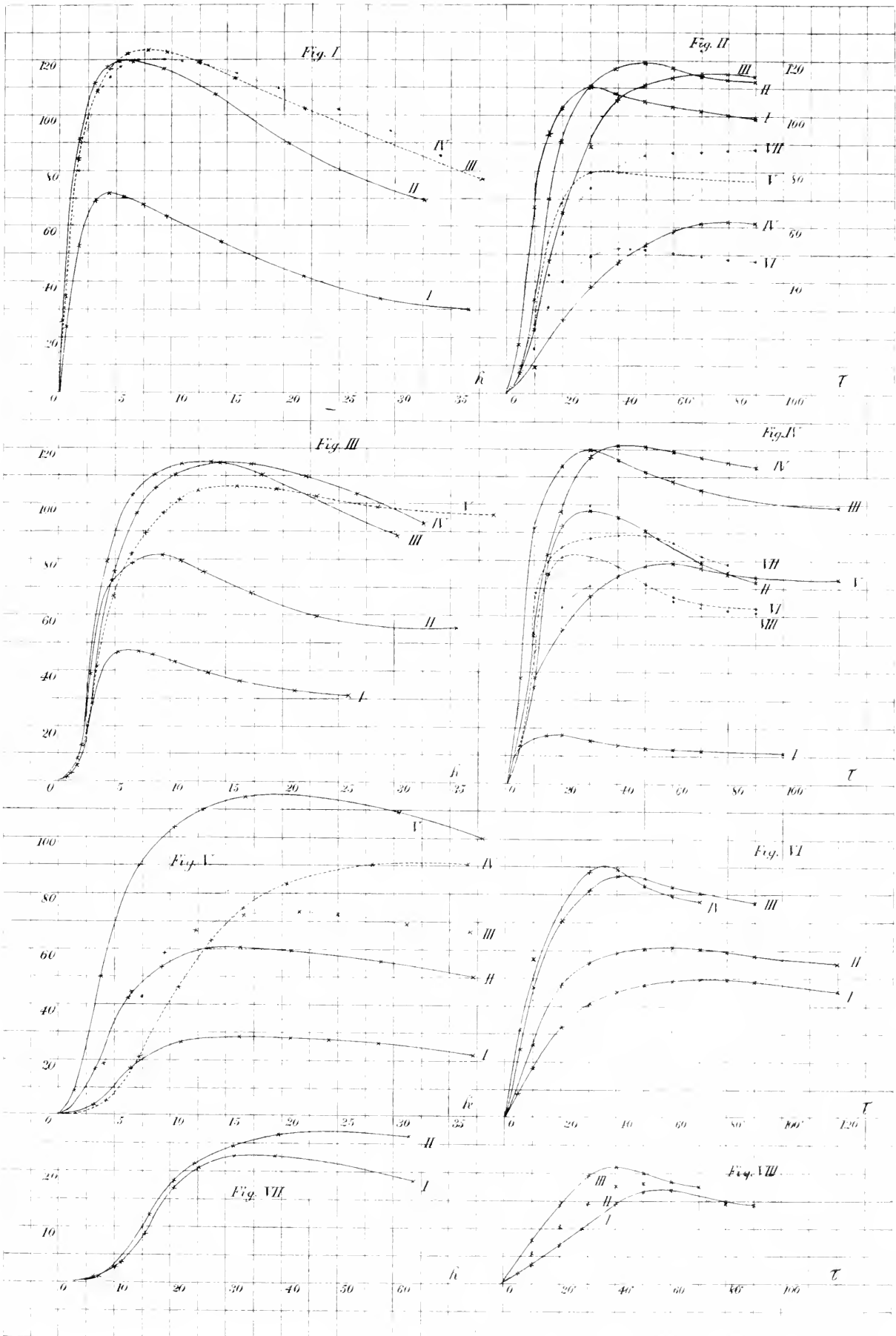




PLATE XXX.

# Plate XXX.

*Fig. IX.*—Obtained by twisting nickel wires ( $r = 0.50$ ) in varying magnetizing fields.

Curve I. for  $\tau = \pm 30^\circ$ ,  $r = 0.5$ ;    Curve II. for  $\tau = \pm 45^\circ$ ,  $r = 0.5$ ;  
 „ III. „  $\tau = \pm 60^\circ$ ,  $r = 0.5$ ;    „ IV. for  $\tau = \pm 90^\circ$ ,  $r = 0.5$ ;  
 „ V. „  $\tau = \pm 60^\circ$ ,  $r = 0.43$ ;    „ VI. for  $\tau = \pm 90^\circ$ ,  $r = 0.43$ .

*Fig. X.*—Obtained by twisting nickel wire,  $\tau$  being variable.

Curve I. for  $\delta = 5.0$ ,  $r = 0.5$ ;    Curve II. for  $\delta = 9.8$ ,  $r = 0.5$ ,  
 „ III. „  $\delta = 10.5$ ,  $r = 0.5$ ,  $w = 5$ ;    „ IV. „  $\delta = 9.8$ ,  $r = 0.5$ ,  $w = 8$ .  
 „ V. „  $\delta = 32.8$ ,  $r = 0.43$ ;    „ VI. „  $\delta = 9.9$ ,  $r = 0.43$ ,  $w = 4$ .

*Fig. XI.*—Obtained by reversing the direction of the magnetizing force, with nickel wire ( $r = 0.5$ ),  $\delta$  being variable.

Curve I. for  $\tau = \pm 30^\circ$ ;    Curve II. for  $\tau = \pm 90^\circ$ ;  
 „ III. „  $\tau = \pm 180^\circ$ ;    „ IV. „  $\tau = \pm 60^\circ$ ,  $w = 1$ ;  
 „ V. „  $\tau = \pm 60^\circ$ ,  $w = 8$ .

*Fig. XII.*—Obtained by reversing the direction of magnetizing force, with nickel wire ( $r = 0.43$ ),  $\delta$  being variable.

Curve I. for  $\tau = \pm 60^\circ$ ;    Curve II. for  $\tau = \pm 360^\circ$ ;  
 „ III. „  $\tau = \pm 60^\circ$ ,  $w = 1$ ;    „ IV. for  $\tau = \pm 60^\circ$ ,  $w = 8$ .

*Fig. XIII.*—Obtained by reversal with nickel wires ( $r = 0.5$  and  $r = 0.43$ ),  $\tau$  being variable.

Curve I. for  $\delta = \pm 10.6$ ,  $r = 0.5$ ;    Curve II. for  $\delta = \pm 1.5$ ,  $r = 0.5$ ,  $w = 5$ ;  
 „ III. „  $\delta = \pm 9.8$ ,  $r = 0.5$ ,  $w = 5$ ;    „ IV. „  $\delta = \pm 9.8$ ,  $r = 0.43$ ;  
 „ V. „  $\delta = \pm 5.0$ ,  $r = 0.43$ ,  $w = 5$ ;    „ VI. „  $\delta = \pm 25.1$ ,  $r = 0.43$ ,  $w = 5$ .

*Fig. XIV.*—Obtained by reversal for  $\tau = \pm 60^\circ$ , with nickel wires of different thickness,  $\delta$  being variable.

Curve I. for  $r = 0.50$ ;    Curve II. for  $r = 0.65$ ;  
 „ III. „  $r = 0.81$ ;    „ IV. „  $r = 1.00$ ;  
 „ V. „  $r = 0.65$ ,  $w = 5$ .

*Fig. XV.*—Obtained by reversal in  $\delta = \pm 19.7$ , with nickel wires of different thickness,  $\tau$  being variable.

Curve I. for  $r = 0.50$ ;    Curve II. for  $r = 0.65$ ;  
 „ III. „  $r = 0.81$ ;    „ IV. „  $r = 1.00$ .

*Fig. XVI.*—Obtained by reversal,  $\tau$  being variable.

Curve I. for  $r = 0.81$ ,  $\delta = 3.4$ ,  $w = 8$ ; Curve II. for  $r = 1.00$ ,  $\delta = 6.3$ ,  $w = 8$ .

















